Appendix C: Climate impacts and adaptation actions for white-tailed ptarmigan

Figure C.1. White-tailed ptarmigan

The Washington-British Columbia Transboundary Climate-Connectivity Project engaged science-management partnerships to identify potential climate impacts on wildlife habitat connectivity and adaptation actions for addressing these impacts in the transboundary region of Washington and British Columbia.[i] Project partners identified potential climate impacts and adaptation actions for a suite of case study species, a vegetation system, and a region chosen for their shared priority status among project partners, representation of diverse habitat types and climate sensitivities, and data availability. This appendix describes potential climate impacts and adaptation actions for white-tailed ptarmigan (*Lagopus leucura*).

The white-tailed ptarmigan is a small grouse found in high elevation alpine habitats across western North America. A local migrant, white-tailed ptarmigans remain in the alpine zone year round, shifting between slightly higher elevations in summer and slightly lower elevations in winter.[2] Populations are patchily distributed among isolated areas of alpine habitat. Though long-distance movements are rarely observed, genetic similarities among populations suggest that longer distance dispersal events happen at least occasionally, but that large areas of unsuitable low elevation habitat may act as barriers to movement.[3-4]

Future climate change may present additional challenges and needs for white-tailed ptarmigan habitat connectivity.[5-6] First, climate change may impact white-tailed ptarmigan core habitat and dispersal habitat in ways that may make them more or less permeable to movement. Second, existing white-tailed ptarmigan core habitat and dispersal habitat may be distributed on the landscape in ways that make them more or less able to accommodate climate-driven shifts in white-tailed ptarmigan distributions. For such reasons, connectivity enhancement has become the most frequently recommended climate adaptation strategy for biodiversity conservation.[7] However, little work has been done to translate this broad strategy into specific, on-the-ground actions. Furthermore, to our knowledge, no previous work has identified specific climate impacts or adaptation responses for white-tailed ptarmigan habitat connectivity. To address these needs, we describe here a novel effort to identify and address potential climate impacts on white-tailed ptarmigan habitat connectivity in the transboundary region of Washington and British Columbia.

Potential climate impacts on habitat connectivity

To identify potential climate impacts on transboundary white-tailed ptarmigan habitat connectivity, project partners created a conceptual model that identifies the key landscape features and processes expected to influence white-tailed ptarmigan habitat connectivity, which of those are expected to be influenced by climate, and how (Appendix C.2). Simplifying complex ecological systems in such a way can make it easier to identify specific climate impacts and adaptation actions. For this reason, conceptual models have been promoted as useful adaptation tools, and have been applied in a variety of other systems.[8] The ptarmigan conceptual model was developed using peer-reviewed articles and reports, as

[i] This report is Appendix C of the Washington-British Columbia Transboundary Climate-Connectivity Project; for more information about the project's rationale, partners, methods, and results, see Krosby et al. (2016).[1]

well as project participant expertise. That said, the resulting model is intentionally simplified, and should not be interpreted to represent a comprehensive assessment of the full suite of landscape features and processes contributing to white-tailed ptarmigan habitat connectivity.

Project participants used conceptual models in conjunction with maps of projected future changes in species distributions, vegetation communities, and relevant climate variables to identify potential impacts on white-tailed ptarmigan connectivity. Because a key project goal was to increase practitioner partners' capacity to access, interpret, and apply existing climate and connectivity models to their decision-making, we relied on a few primary datasets that are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Washington Connected Landscapes Project,[9,10] future climate projections from the Integrated Scenarios of the Pacific Northwest Environment[11] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[12] and models of projected range shifts and vegetation change produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.[13]

Key impacts on transboundary white-tailed ptarmigan habitat connectivity identified via this approach include changes in areas of white-tailed ptarmigan climatic suitability, changes in vegetation, and declines in the amount and duration of snowpack.

Changes in areas of climatic suitability

Climate change may affect white-tailed ptarmigan habitat connectivity by changing the extent and location of areas of climatic suitability for the species; this may render some existing core habitat areas and dispersal habitat unsuitable for white-tailed ptarmigan, and/or create new areas of suitability. Climatic niche models (CNM) or other range shift models are currently unavailable for white-tailed ptarmigan across the transboudary region. However, projected increases in temperature (Appendix C.4: Increase in Average Annual Daytime Temperature) may be physiologically stressful for this cold-adapted species,[14] leading to range contractions in areas that become thermally unsuitable.

Changes in vegetation

The white-tailed ptarmigan lives and breeds in alpine habitats above treeline. Changes in the distribution and quality of alpine habitats in the transboundary region could therefore be expected to affect white-tailed ptarmigan habitat connectivity.

Two types of models are available that estimate future changes in vegetation for the transboundary region: climatic niche models and mechanistic models (Appendix C.3).[ii] Both types of models are based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.[iii] Both

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[ii] Climatic niche vegetation models mathematically define the climatic conditions within a given vegetation type's current distribution and then project where on the landscape those conditions are expected to occur in the future. These models do not incorporate other important factors that determine vegetation such as soil suitability, dispersal, competition, and fire. In contrast, mechanistic vegetation models do incorporate these ecological processes as well as projected climate changes and potential effects of carbon dioxide fertilization. However, mechanistic models only projected changes to very general vegetation types such as cold forest, shrub steppe, or grassland.

[iii] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-

models also use the A2 (high) emissions scenario.[iv] Both mechanistic and climatic niche vegetation models project that cold forest vegetation types will shift higher in elevation and replace open alpine habitat (Appendix C.3), which could reduce the total area of habitat available for ptarmigan within their current range. Increased risk of wildfire (Appendix C.4: Days with High Fire Risk) may help to maintain patches of open habitat at high elevations as the treeline rises. Rising treelines could affect connectivity if it leads to increased fragmentation and isolation of remaining alpine habitat patches. Because white-tailed ptarmigans usually disperse over relatively short distances, populations living on lower elevation mountain peaks may have difficulty dispersing to higher, cooler peaks as treeline rises.

Declining amount and duration of snowpack

Projected declines in the amount and duration of snowpack (Appendix C.4: Spring (April 1st) Snowpack; Snow Season Length) may affect ptarmigan habitat connectivity by altering the amount and distribution of core habitat. Ptarmigan reproduction is sensitive to the timing and amount of snowfall; nesting occurs after snowmelt, and late season snow storms or rain storms (Appendix C.4: Total Spring Precipitation) may increase reproductive failure.[4] Thus, a shorter snow season may increase core habitat areas through increased nesting suitability. However, if late season storms become more common, this could negatively affect ptarmigan reproductive success.

Adaptation responses

After identifying potential climate impacts on white-tailed ptarmigan habitat connectivity, project participants used conceptual models to identify which relevant landscape features or processes could be affected by management activities, and subsequently what actions could be taken to address projected climate impacts (Appendix C.2). Key adaptation actions identified by this approach fall under three main categories: those that address potential climate impacts on white-tailed ptarmigan habitat connectivity, those that address novel habitat connectivity needs for promoting climate-induced shifts in white-tailed ptarmigan distributions, and those that identify spatial priorities for implementation.

Addressing climate impacts on white-tailed ptarmigan habitat connectivity

Actions to address the potential for white-tailed ptarmigan habitat to become increasingly isolated and fragmented include:

- Monitoring and responding to human-caused trampling of alpine vegetation and other recreation-related impacts on alpine habitats.
- Monitoring changes in treeline using LIDAR remote sensing, which would help evaluate the rate of change and provide insight into potential future habitat loss.
- Removing trees that encroach into alpine habitats. Note that this may be ineffective or undesirable in the long term or over large scales, due to its labor intensity and the need for lower elevation habitats to shift upward to adapt to change. Therefore, consider implementing only as a last resort if populations reach critically low levels.

HadCM3 could be considered a “hot-dry” future, while the CGCM3.1(T47) could be considered a “warm-wet” future within the Pacific Northwest.

[iv] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, “business as usual” scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

- Considering the benefits and risks of investing in intensive ptarmigan habitat management and restoration activities for populations living at the warm edge of the range. In marginal habitat locations, consider identifying and implementing habitat management activities with broader ecosystem benefits, rather than those that benefit only ptarmigan.

Enhancing connectivity to facilitate range shifts

Actions to help ptarmigan adjust its range to track shifts in areas of climatic suitability include:

- Maintaining and restoring corridors that span elevation and climatic gradients (Appendix C.1),[10] which may help promote ptarmigan dispersal into cooler habitats as the climate warms.
- Considering assisted migration of ptarmigan to unoccupied or sparsely occupied alpine habitats at higher elevations and latitudes; this may particularly useful for source populations isolated by large areas of unsuitable low elevation habitat, and receiving habitats projected to maintain alpine vegetation.

Spatial priorities for implementation

Spatial priorities for implementation of the adaptation actions described above include:

- Areas projected to maintain persistent alpine vegetation in the future (Appendix C.3).
- Landscape integrity and climate-gradient corridors (Appendix C.1).[9-10] Though little is known about how ptarmigan disperse among isolated patches of alpine habitat, it is likely that linkages that are in good natural condition (i.e., landscape integrity corridors) and that span climate gradients (i.e., climate-gradient corridors) may promote ptarmigan movement among alpine habitats and to cooler patches as the climate warms.

Research Needs

Additional Research

Future research that could help inform white-tailed ptarmigan habitat connectivity conservation under climate change includes:

- Developing fine-scale maps of current ptarmigan populations (as opposed to general range boundaries). This could help identify vulnerable populations and provide useful information on existing and potential future habitat connectivity.
- Researching what types of landscape features or vegetation types facilitate or inhibit ptarmigan movement. Little is known about how white-tailed ptarmigan select dispersal habitat.
- Developing transboundary ptarmigan habitat connectivity models. Such models would help identify core habitat areas and corridors contributing to ptarmigan habitat connectivity; these may be used as priority areas for the adaptation actions described above.
- Identifying climate resilient white-tailed ptarmigan core habitat areas. Overlay projected changes in vegetation (Appendix C.3) and snowpack (Appendix C.4). Areas where alpine habitat is retained and snowpack declines or remains unchanged may be most likely to support future ptarmigan populations. These climate-resilient habitat areas may be used as priority areas for the adaptation actions described above.
- Developing transboundary ptarmigan climatic niche models. Such models would be helpful for identifying which existing areas of suitable habitat are most likely to remain climatically suitable for ptarmigan, and which may become unsuitable. Areas of stable or increased suitability may be used as priority areas for adaptation actions described above.

References

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3. Fedy, B. C., Martin, K., Ritland, C. and J. Young, 2008. Genetic and ecological data provide incongruent interpretations of population structure and dispersal in naturally subdivided populations of white-tailed ptarmigan (*Lagopus leucura*). *Molecular Ecology* 17:1905–1917.
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10. Washington Wildlife Habitat Connectivity Working Group. 2011. Washington Connected Landscapes Project: Climate gradient corridors report. Washington Departments of Fish and Wildlife, and Transportation. Olympia, WA. www.waconnected.org.
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13. Pacific Northwest Climate Change Vulnerability Assessment (PNWCCVA). http://www.climatevulnerability.org/
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Glossary of Terms

Assisted migration – Species and populations are deliberately planted or transported to new suitable habitat locations, typically in response to declines in historic habitat quality resulting from rapid environmental change, principally climate change.

Centrality — Refers to a group of landscape metrics that rank the importance of habitat patches or linkages in providing movement across an entire network, i.e., as "gatekeepers" of flow across a landscape.[v]

Connectivity — Most commonly defined as the degree to which the landscape facilitates or impedes movement among resource patches.[vi] Can be important for maintaining ecological, population-level, or evolutionary processes.

Core Areas — Large blocks (10,000+ acres) of contiguous lands with relatively high landscape permeability.

Corridor — Refers to modeled movement routes or physical linear features on the landscape (e.g., continuous strips of riparian vegetation or transportation routes). In this document, the term "corridor" is most often used in the context of modeled least-cost corridors, i.e., the most efficient movement pathways for wildlife and ecological processes that connect HCAs or core areas. These are areas predicted to be important for migration, dispersal, or gene flow, or for shifting ranges in response to climate change and other factors affecting the distribution of habitat.

Desiccation – Extreme water deprivation, or process of extreme drying.

Dispersal — Relatively permanent movement of an individual from an area, such as movement of a juvenile away from its place of birth.

Fracture Zone — An area of reduced permeability between core areas. Most fracture zones need significant restoration to function as reliable linkages. Portions of a fracture zone may be potential linkage zones.

Habitat Connectivity — See Connectivity.

Landscape Connectivity — See Connectivity.

Permeability — The ability of a landscape to support movement of plants, animals, or processes.

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[v] Carroll, C. 2010. Connectivity analysis toolkit user manual. Version 1.1. Klamath Center for Conservation Research, Orleans, California. Available at www.connectivitytools.org (accessed January 2016).

[vi] Taylor, P. D., L. Fahrig, K. Henein, and G. Merriam. 1993. Connectivity is a vital element of landscape structure. *Oikos* 68: 571-573.

Pinch point — Portion of the landscape where movement is funneled through a narrow area. Pinch points can make linkages vulnerable to further habitat loss because the loss of a small area can sever the linkage entirely. Synonyms are bottleneck and choke point.

Refugia – Geographical areas where a population can survive through periods of unfavorable environmental conditions (e.g., climate-related effects).

Thermal barriers – Water temperatures warm enough to prevent migration of a given fish species. These barriers can prevent or delay spawning for migrating salmonids.

Appendices C.1-4

Appendices include all materials used to identify potential climate impacts on habitat connectivity for case study species, vegetation systems, and regions. For white-tailed ptarmigan, these materials include:

Appendix C.1. Habitat connectivity models
Appendix C.2. Conceptual model of habitat connectivity
Appendix C.3. Projected changes in vegetation communities
Appendix C.4. Projected changes in relevant climatic variables

All maps included in these appendices are derived from a few primary datasets, chosen because they are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Washington Connected Landscapes Project,[9,10] future climate projections from the Integrated Scenarios of the Pacific Northwest Environment[11] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[12] and models of projected range shifts and vegetation change produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.[13]

All maps are provided at three geographic extents corresponding to the distinct geographies of the three project partnerships (Fig. C.2):

i. **Okanagan Nation Territory**, the assessment area for project partners: Okanagan Nation Alliance and its member bands and tribes, including Colville Confederated Tribes.

ii. **The Okanagan-Kettle Region**, the assessment area for project partners: Transboundary Connectivity Working Group (i.e., the Washington Habitat Connectivity Working Group and its BC partners).

iii. **The Washington-British Columbia Transboundary Region**, the assessment area for project partners: BC Parks; BC Forests, Lands, and Natural Resource Operations; US Forest Service; and US National Park Service.

All project reports, data layers, and associated metadata are freely available online at:
https://nplcc.databasin.org/galleries/5a3a424b36ba4b63b10b8170ea0c915e

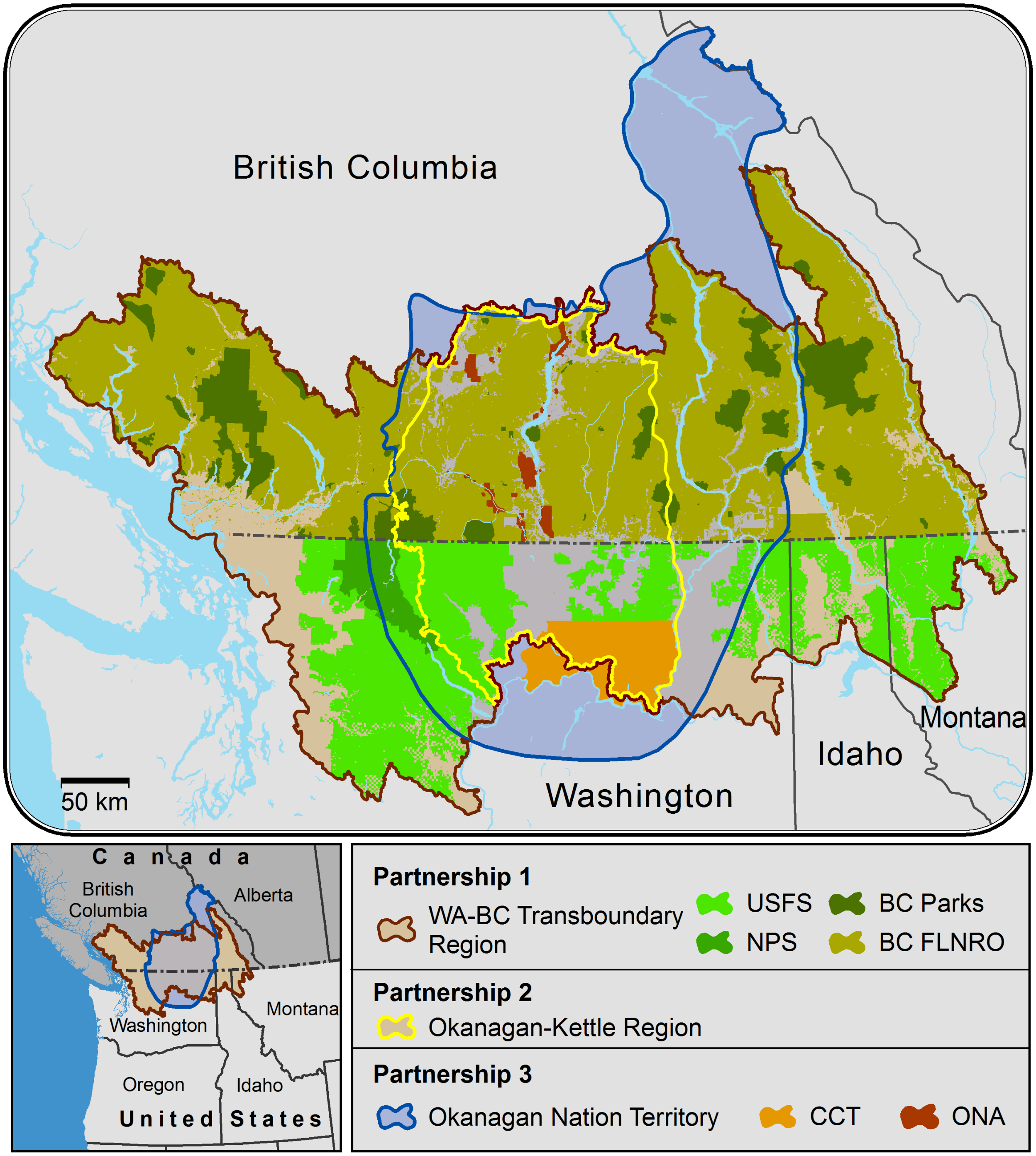


Figure C.2. Project partners and assessment areas.

Appendix C.1. Habitat Connectivity Models

Habitat connectivity models are available from the Washington Connected Landscapes Project.[vii] These models can be used to prioritize areas for maintaining and restoring habitat connectivity now and in the future as the climate changes. Available models include species corridor networks, landscape integrity corridor networks, and climate-gradient corridor networks. These models are available at two distinct scales (though for many species, only one scale is available or was selected for use by project participants): 1) **WHCWG Statewide** models span Washington State and surrounding areas of Oregon, Idaho, and British Columbia; 2) **WHCWG Columbia Plateau** models span the Columbia Plateau ecoregion within Washington State, and do not extend into British Columbia.

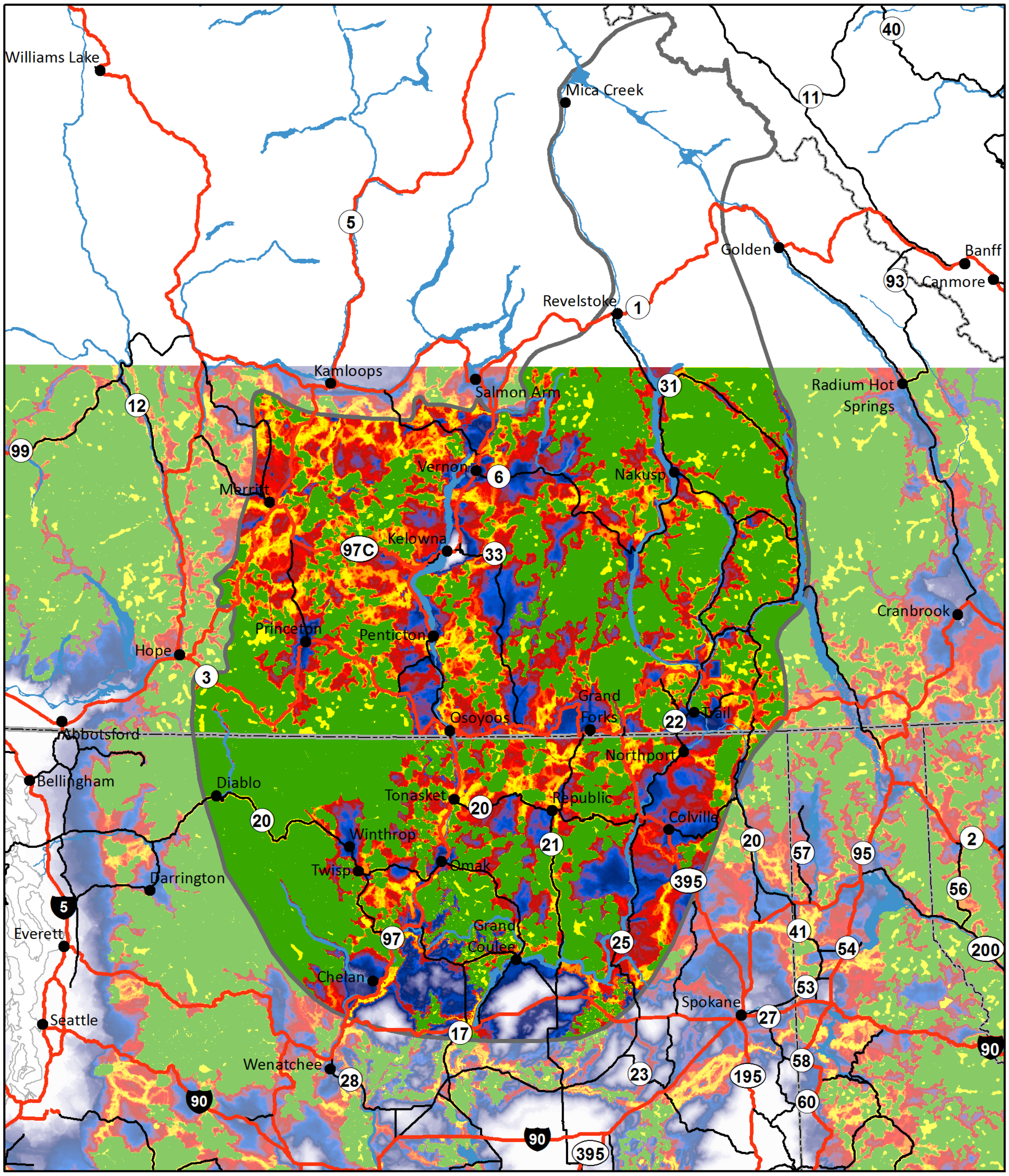
a) **WHCWG Statewide Analysis: Landscape Integrity Corridor Network.**[9] This map shows corridor networks connecting core habitat areas (green polygons) for areas of high landscape integrity (e.g., areas with few roads, agricultural areas, or urban areas). Corridors are represented as yellow areas, with resistance to movement increasing as yellow transitions to blue. Green areas represent large, contiguous core areas of high landscape integrity. The northern extent of this analysis falls just north of Kamloops, BC.

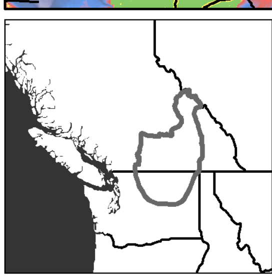
b) **WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity).**[10] This map shows corridors (glowing white areas, with resistance to movement increasing as white fades to black) connecting core habitat areas (polygons, shaded to reflect mean annual temperatures) that are of high landscape integrity (i.e., have low levels of human modification) and differ in temperature by >1 ^{o}C. These corridors thus allow for movement between relatively warmer and cooler core habitat areas, while avoiding areas of low landscape integrity (e.g., roads, agricultural areas, urban areas), and minimizing major changes in temperature along the way (e.g., crossing over cold peaks or dipping into warm valleys). The northern extent of this analysis falls just north of Kamloops, BC.

[vii] For detailed methodology and data layers see http://www.waconnected.org.

Appendix C.1a. WHCWG Statewide Analysis: Landscape Integrity Corridor Network

i) Extent: Okanagan Nation Territory





Landscape Integrity Corridor Network

WHWCG Statewide Analysis

Normalized Least-Cost Corridors

Lower cost

Higher cost

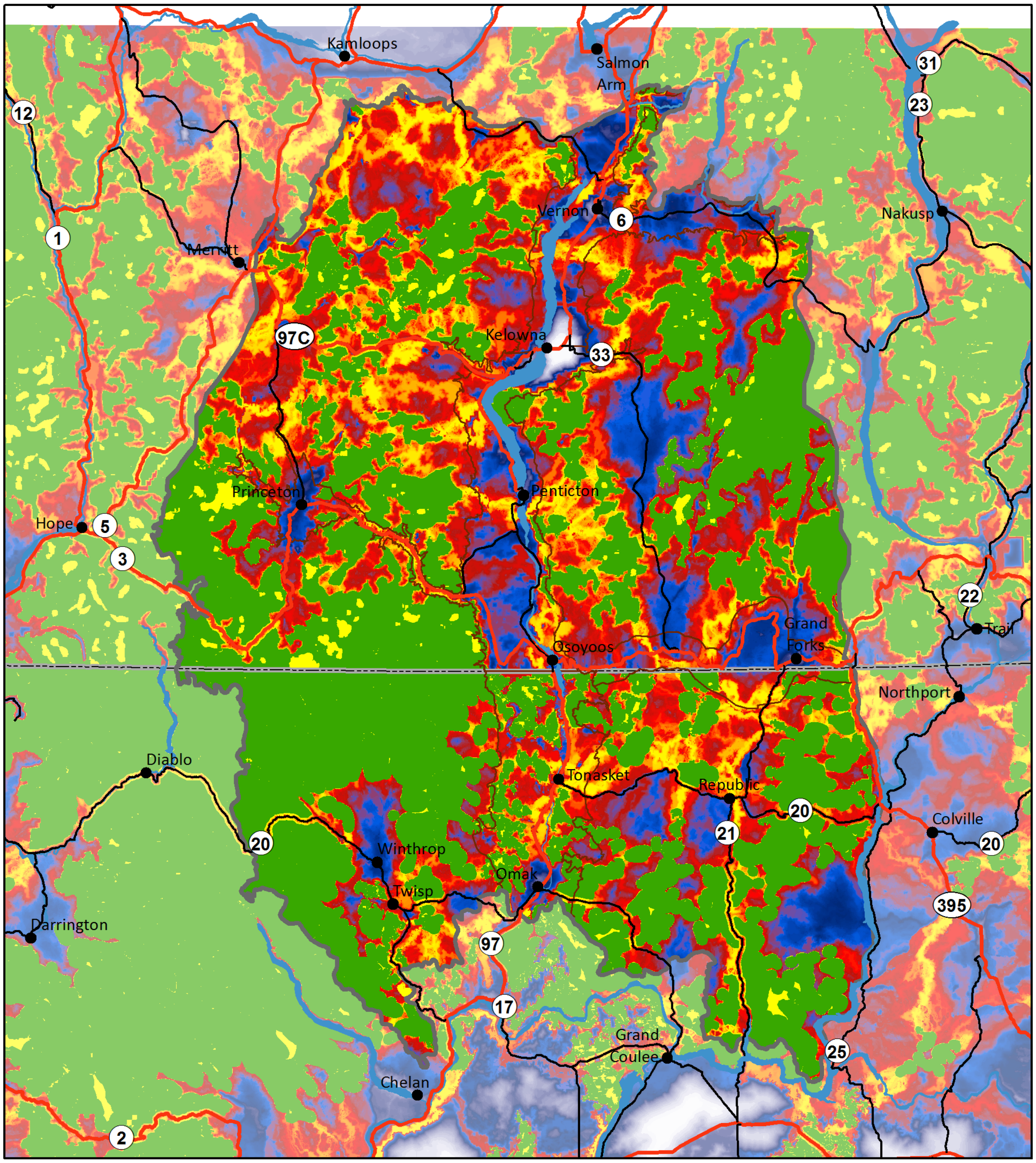
Habitat Concentration Area

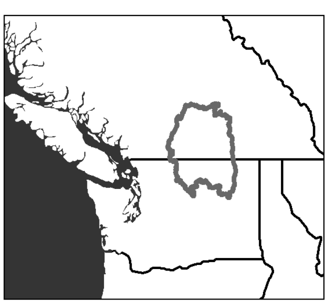
Kilometers

0 25 50 75

Appendix C.1a. WHCWG Statewide Analysis: Landscape Integrity Corridor Network

ii) Extent: Okanagan-Kettle Region





Landscape Integrity Corridor Network

WHCWG Statewide Analysis

Normalized Least-Cost Corridors

Lower cost

Higher cost

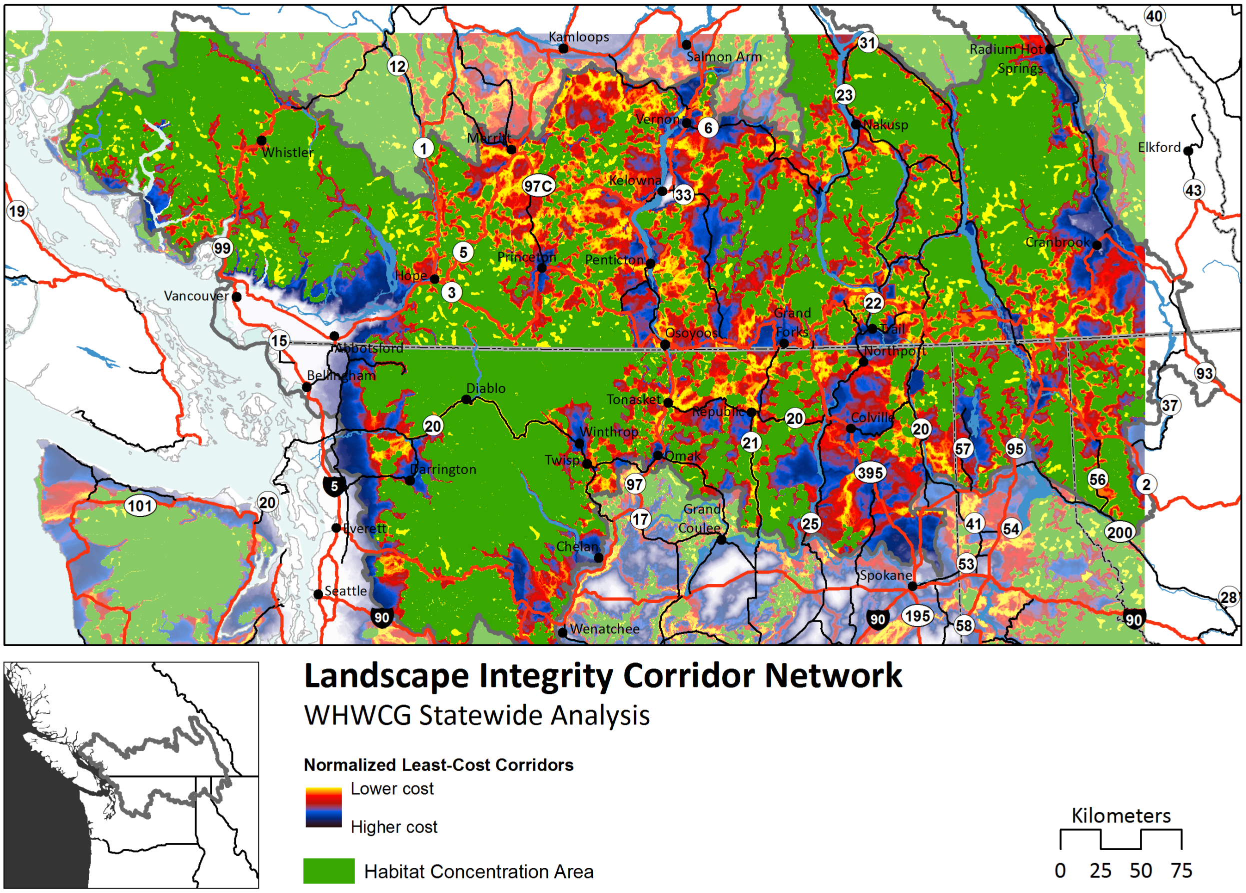
Habitat Concentration Area

Kilometers

0 15 30 45

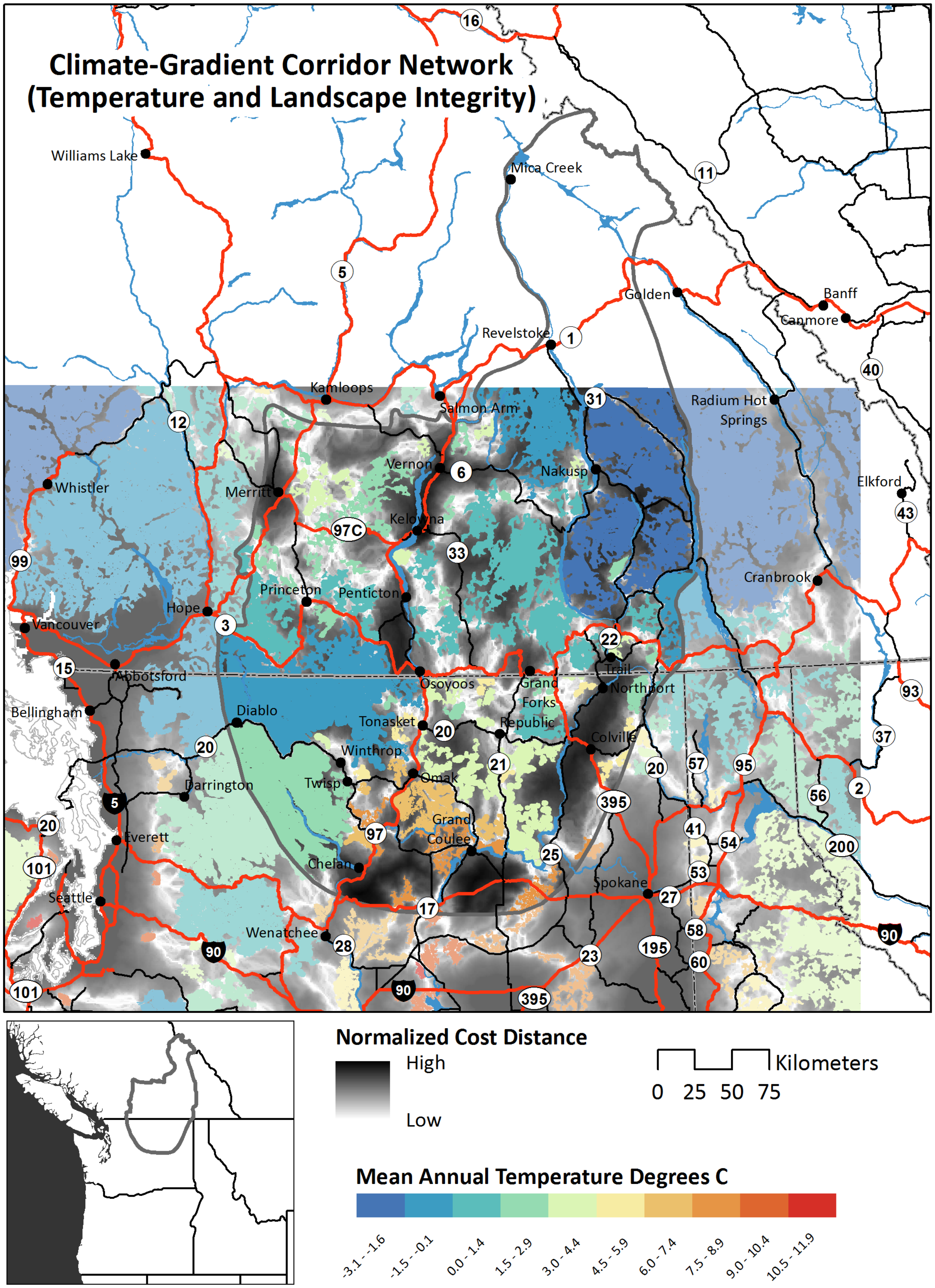
Appendix C.1a. WHCWG Statewide Analysis: Landscape Integrity Corridor Network

iii) Extent: Washington-British Columbia Transboundary Region



Appendix C.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

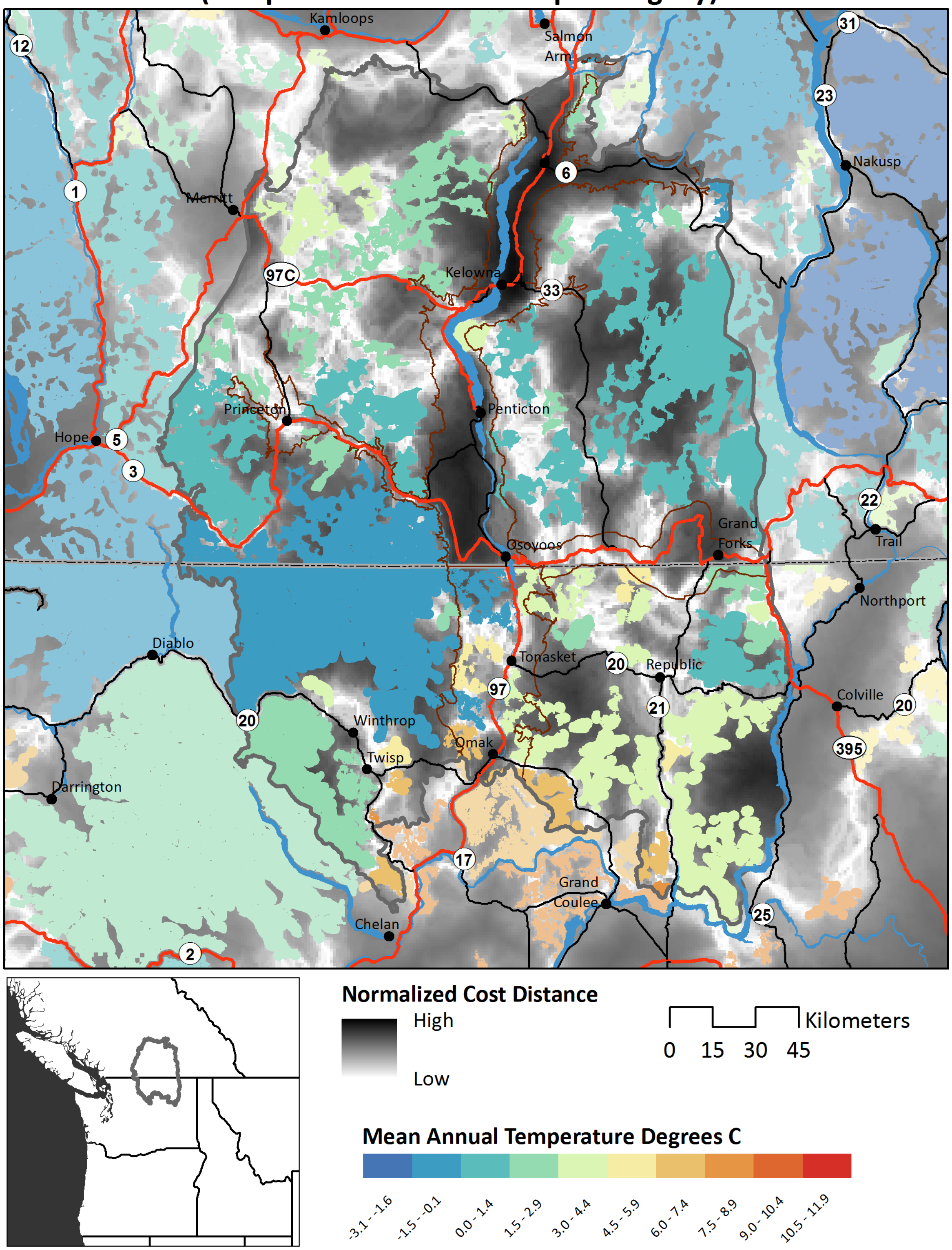
i) Extent: Okanagan Nation Territory



Appendix C.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

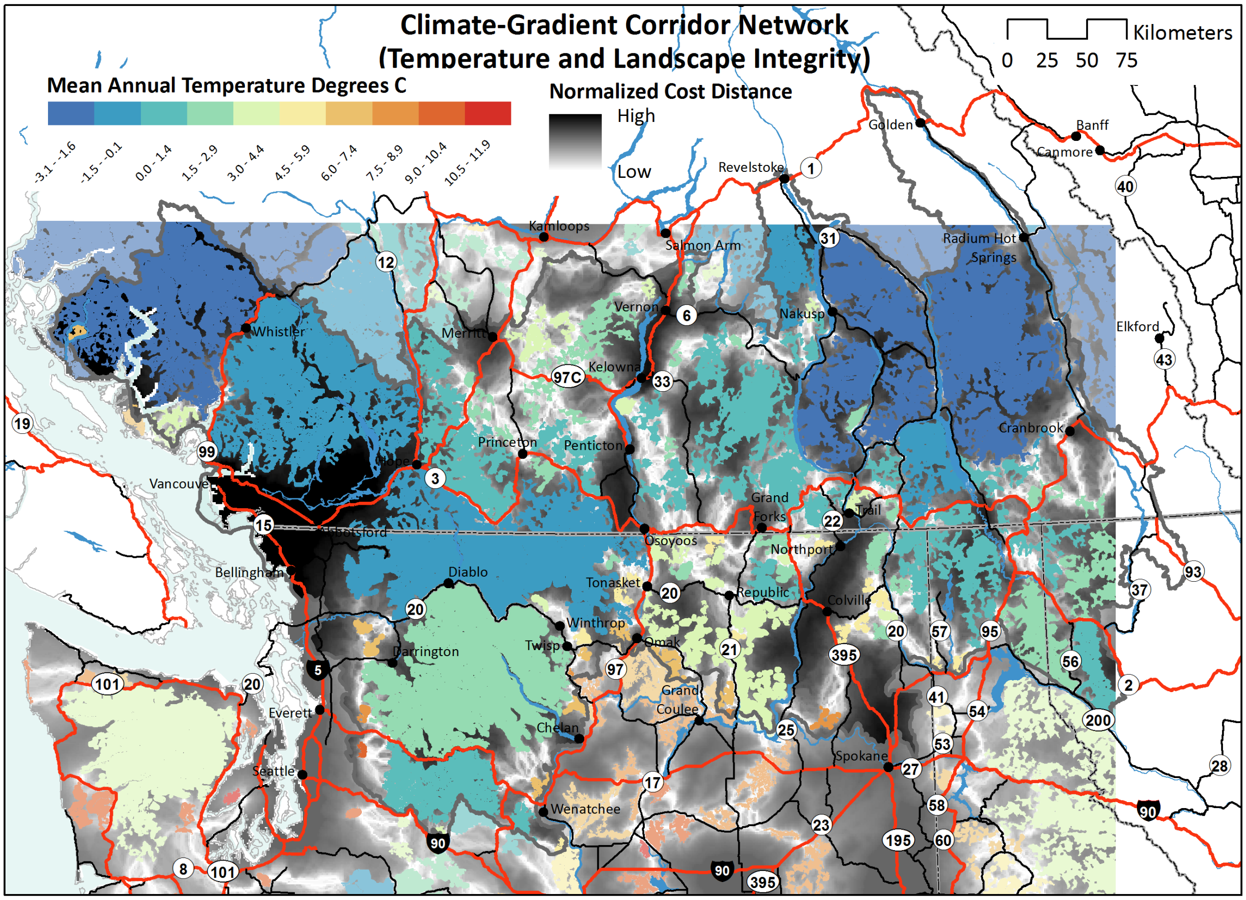
ii) Extent: Okanagan-Kettle Region

**Climate-Gradient Corridor Network
(Temperature and Landscape Integrity)**



Appendix C.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

iii) Extent: Washington-British Columbia Transboundary Region



Appendix C.2. Conceptual Model of Habitat Connectivity

To identify potential climate impacts on transboundary white-tailed ptarmigan habitat connectivity, project partners created a conceptual model that identifies the key landscape features and processes expected to influence white-tailed ptarmigan habitat connectivity, which of those are expected to be influenced by climate, and how. Simplifying complex ecological systems in such a way can make it easier to identify specific climate impacts and adaptation actions. For this reason, conceptual models have been promoted as useful adaptation tools, and have been applied in a variety of other systems.[8] The white-tailed ptarmigan conceptual model was developed using peer-reviewed articles and reports, project participant expertise, and review by species experts. That said, the resulting model is intentionally simplified, and should not be interpreted to represent a comprehensive assessment of the full suite of landscape features and processes contributing to white-tailed ptarmigan habitat connectivity.

Conceptual models illustrate the relationships between the key landscape features (white boxes), ecological processes (rounded corner purple boxes), and human activities (rounded corner blue boxes) that influence the quality and permeability of core habitat and dispersal habitat for a given species. Climatic variables for which data on projected changes are available are highlighted with a yellow outline. Green arrows indicate a positive correlation between linked variables (i.e., as variable x increases variable y increases); note that a positive correlation is not necessarily beneficial to the species. Red arrows indicate a negative relationship between variables (i.e., as variable x increases, variable y decreases); again, negative correlations are not necessarily harmful to the species.

Key references used to create the white-tailed ptarmigan conceptual model included:

Hoffman, R.W. 2006. White-tailed Ptarmigan (*Lagopus leucura*): a technical conservation assessment. USDA Forest Service, Rocky Mountain Region. Available at: http://www.fs.fed.us/r2/projects/scp/assessments/whitetailedptarmigan.pdf [retrieved: 19 May 2015].

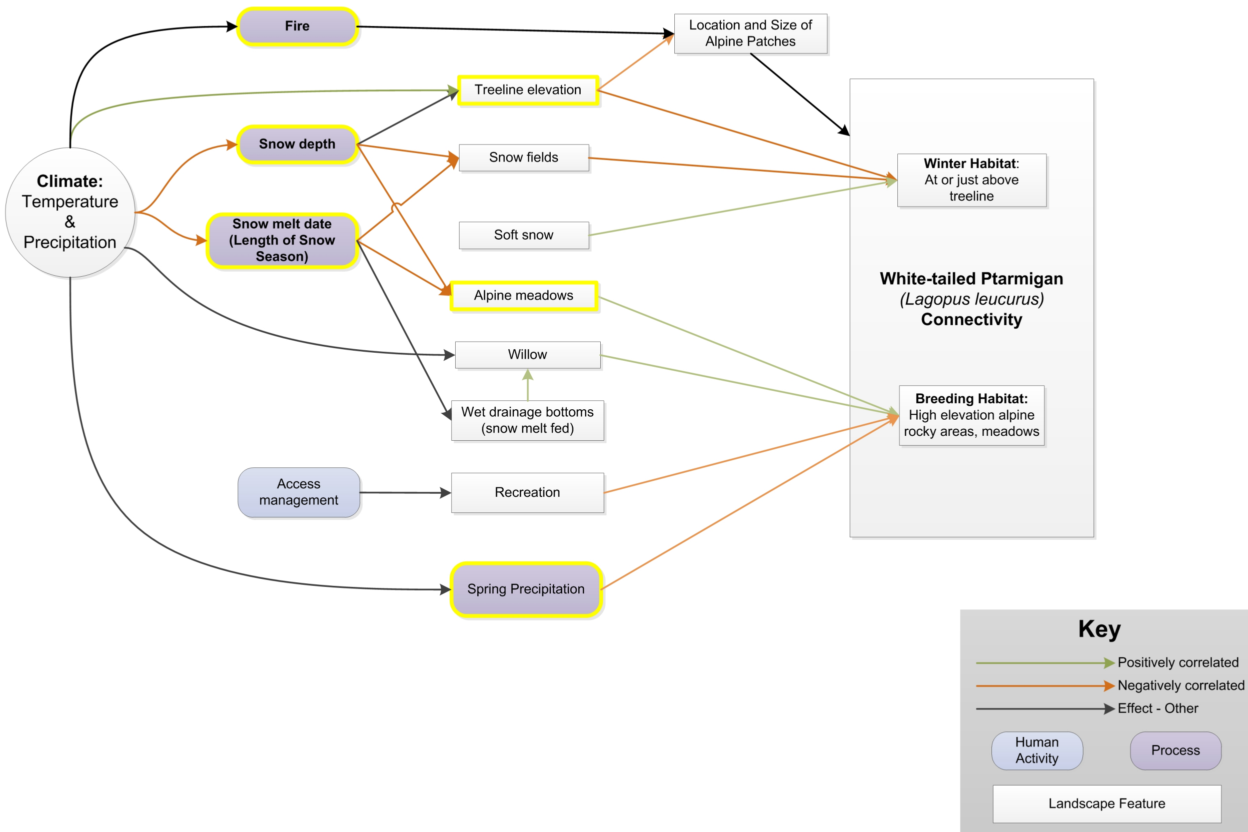
Martin, K., Stacey, P. B., and C.E. Braun. 2000. Recruitment, dispersal, and demographic rescue in spatially-structured white-tailed ptarmigan populations. *The Condor* 102:503-516.

Martin, K., and K.L. Wiebe. 2004. Coping mechanisms of alpine and arctic breeding birds: extreme weather and limitations to reproductive resilience. *Integrative and Comparative Biology* 44:177-185.

Center for Biological Diversity. White-tailed ptarmigan: *Lagopus leucura.* http://www.biologicaldiversity.org/species/birds/white-tailed_ptarmigan/natural_history.html. Accessed on 4/28/2016.

Cornell Laboratory of Ornithology. White-tailed Ptarmigan. http://www.allaboutbirds.org/guide/White-tailed_Ptarmigan/lifehistory. Accessed on 4/28/2016.

Appendix C.2. Conceptual Model of White-tailed Ptarmigan Habitat Connectivity



Appendix C.3. Projected Changes in Vegetation

Two types of models are available that project future changes in vegetation that could affect a species' habitat connectivity: climatic niche models and mechanistic models. Climatic niche vegetation models mathematically define the climatic conditions within a given vegetation type's current distribution and then project where on the landscape those conditions are expected to occur in the future. These models do not incorporate other important factors that determine vegetation such as soil suitability, dispersal, competition, and fire. In contrast, mechanistic vegetation models do incorporate these ecological processes, as well as projected climate changes and the potential effects of carbon dioxide fertilization. However, mechanistic models only project changes to very general vegetation types (e.g., cold forest, shrub steppe, or grassland). Both types of models included below show vegetation model results based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.[viii] Both models also use the A2 (high) emissions scenario.[ix]

a) **Biome Climatic Niche Vegetation Model.**[x] This climatic niche vegetation model shows the projected response of biomes or forest types to projected climate change.

b) **Mechanistic Vegetation Model.**[xi] This mechanistic vegetation model shows simulated vegetation composition and distribution patterns under climate change.

[viii] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

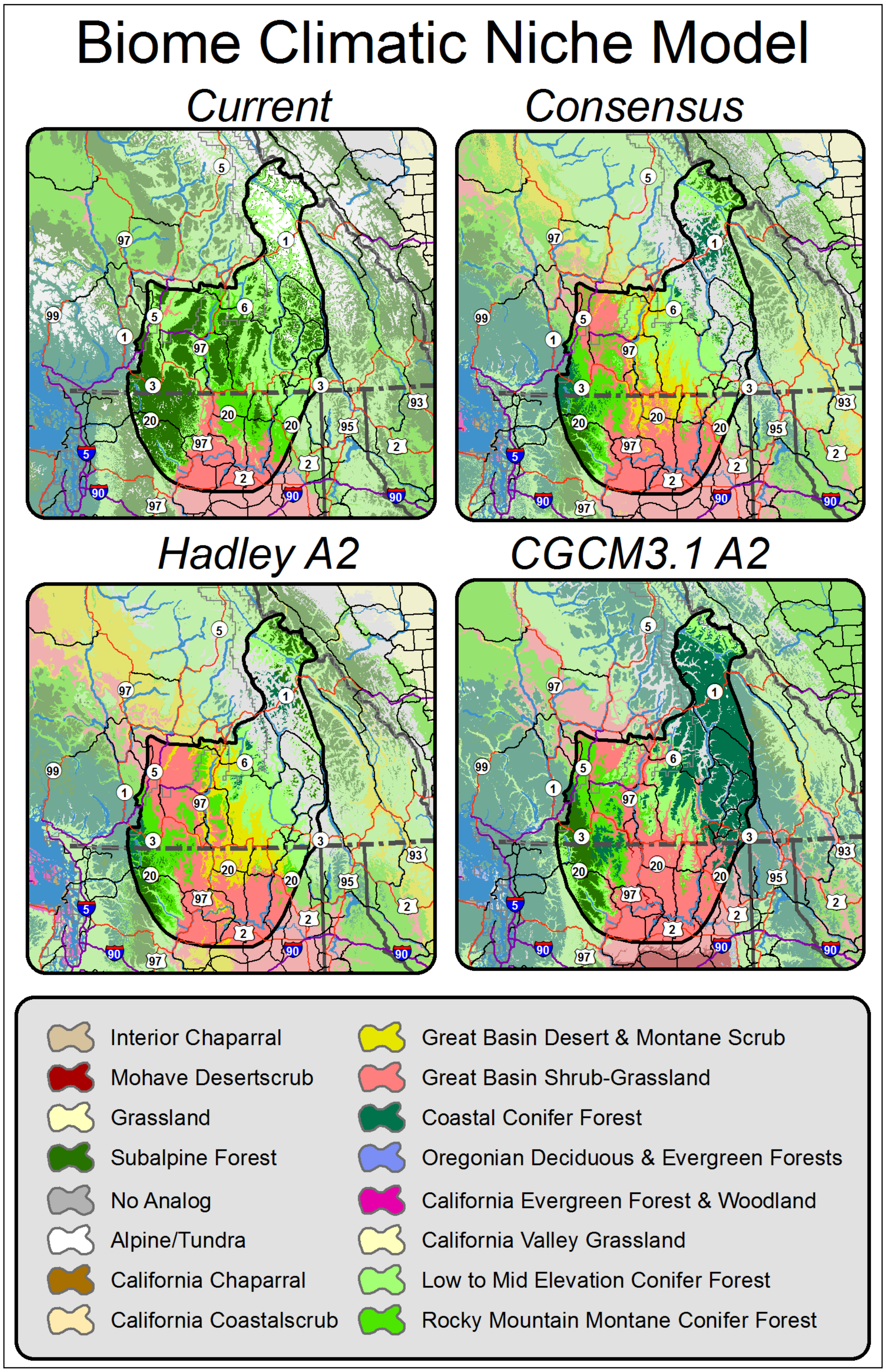
[ix] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

[x] Rehfeldt, G.E., Crookston, N.L., Sánez-Romero, C., Campbell, E.M. 2012. North American vegetation model for land-use planning in a changing climate: a solution to large classification problems. *Ecological Applications* 22: 119-141.

[xi] Shafer, S.L., Bartlein, P.J , Gray, E.M., and R.T. Pelltier. 2015. Projected future vegetation changes for the Northwest United States and Southwest Canada at a fine spatial resolution using a dynamic global vegetation model. *PLoS ONE* 10: e0138759. doi:10.1371/journal.pone.0138759.

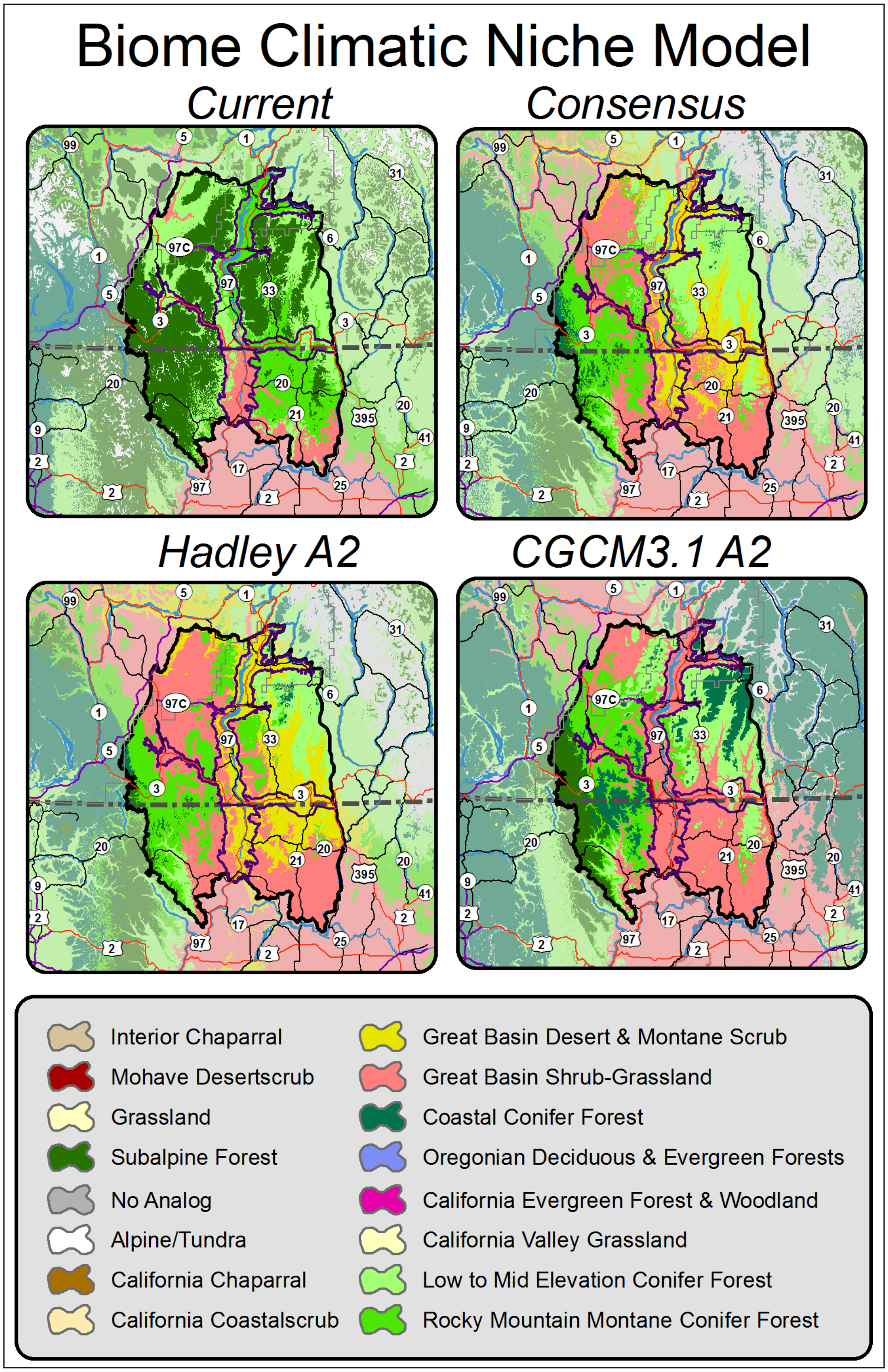
Appendix C.3a. Biome Climatic Niche Model

i) Extent: Okanagan Nation Territory



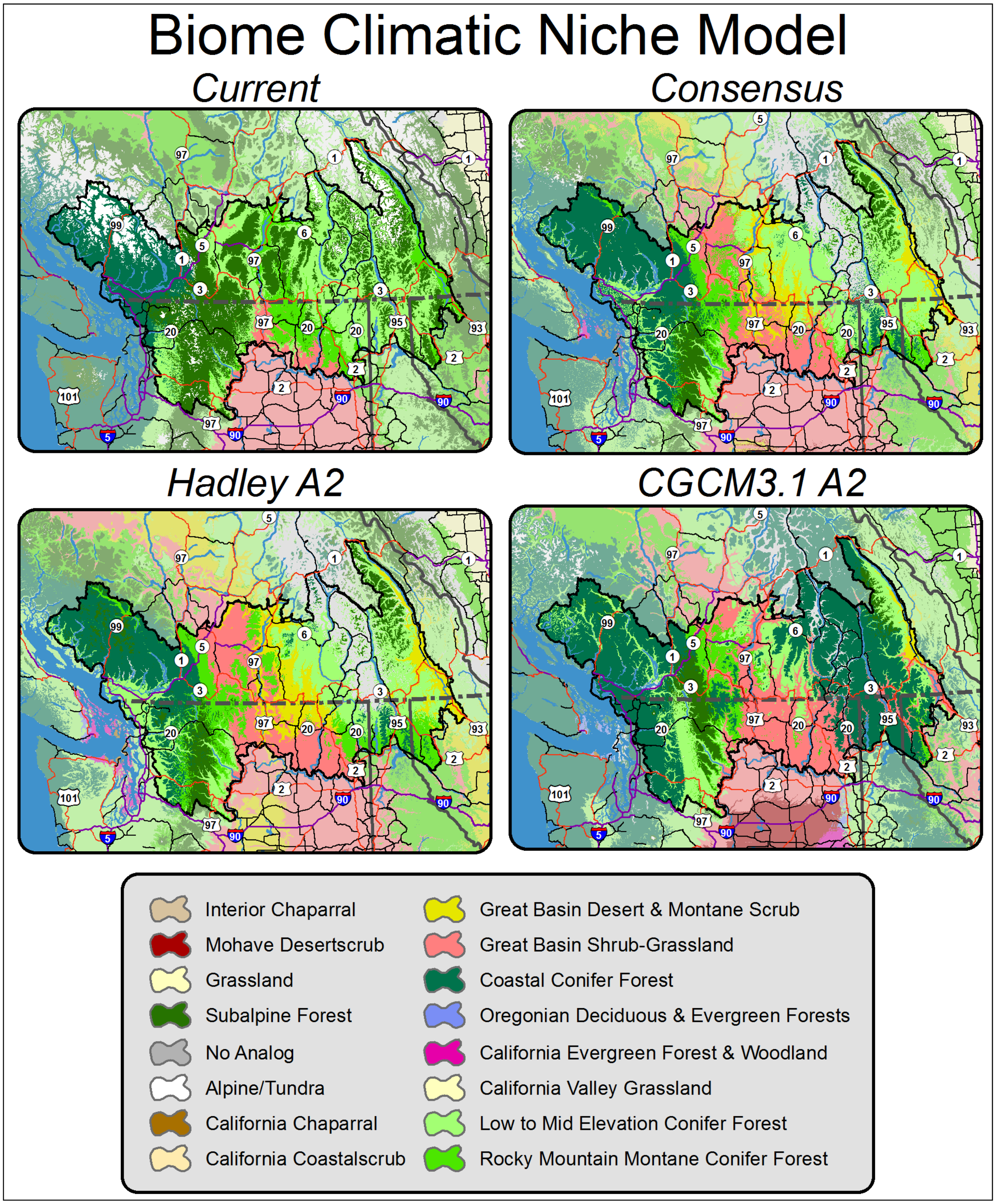
Appendix C.3a. Biome Climatic Niche Model

ii) Extent: Okanagan-Kettle Region



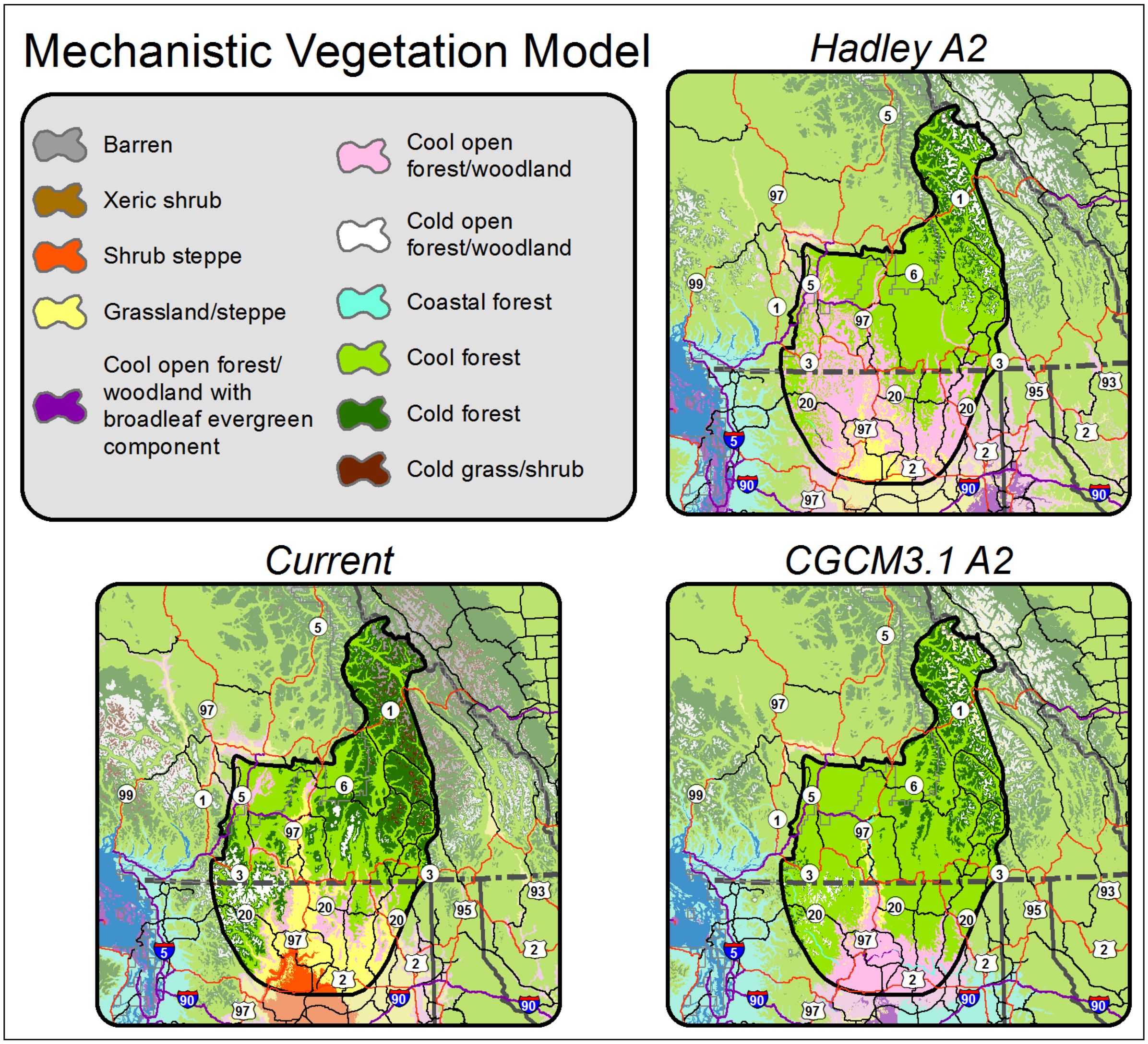
Appendix C.3a. Biome Climatic Niche Model

iii) Extent: Washington-British Columbia Transboundary Region



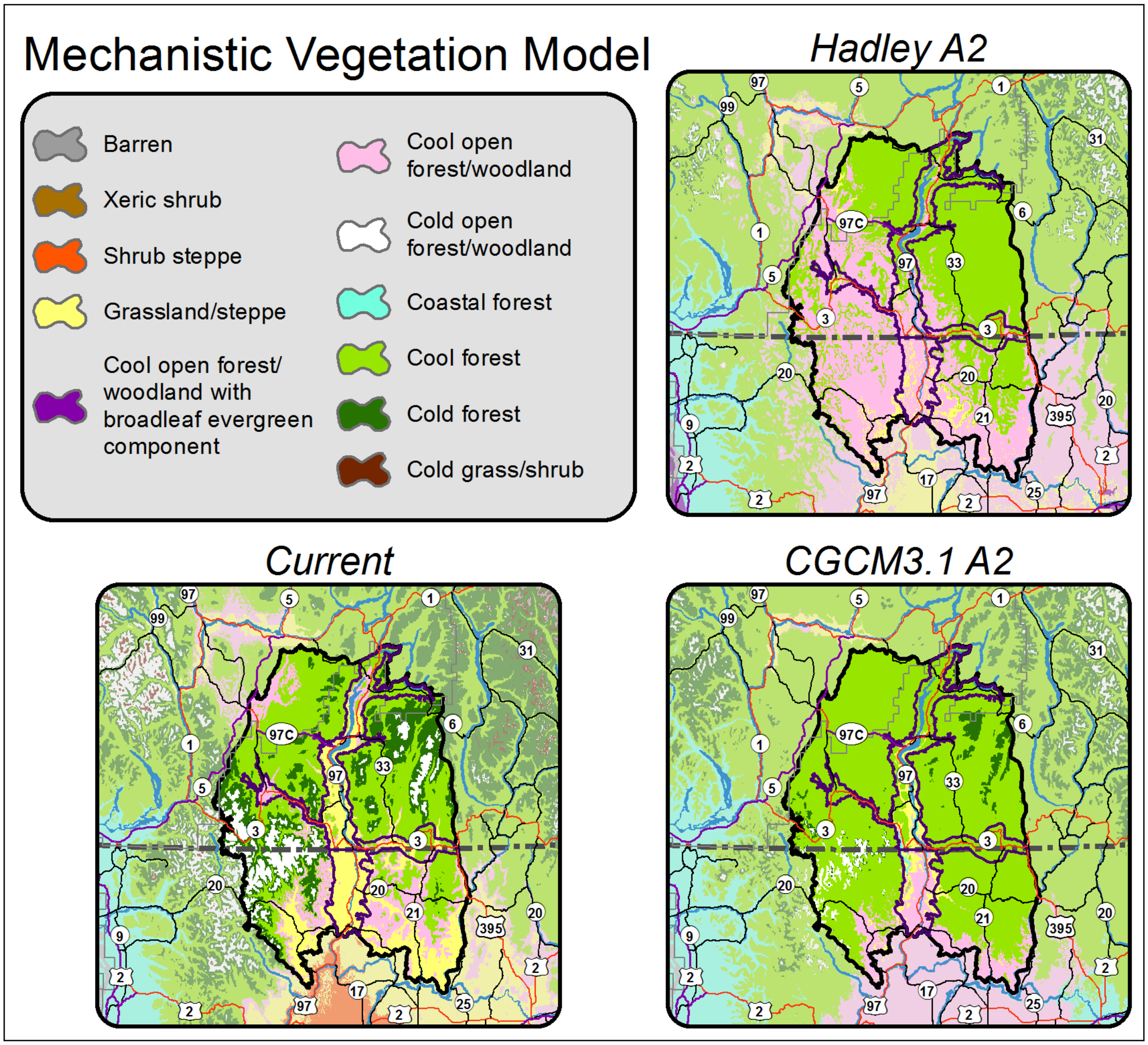
Appendix C.3b. Mechanistic Vegetation Model

i) Extent: Okanagan Nation Territory



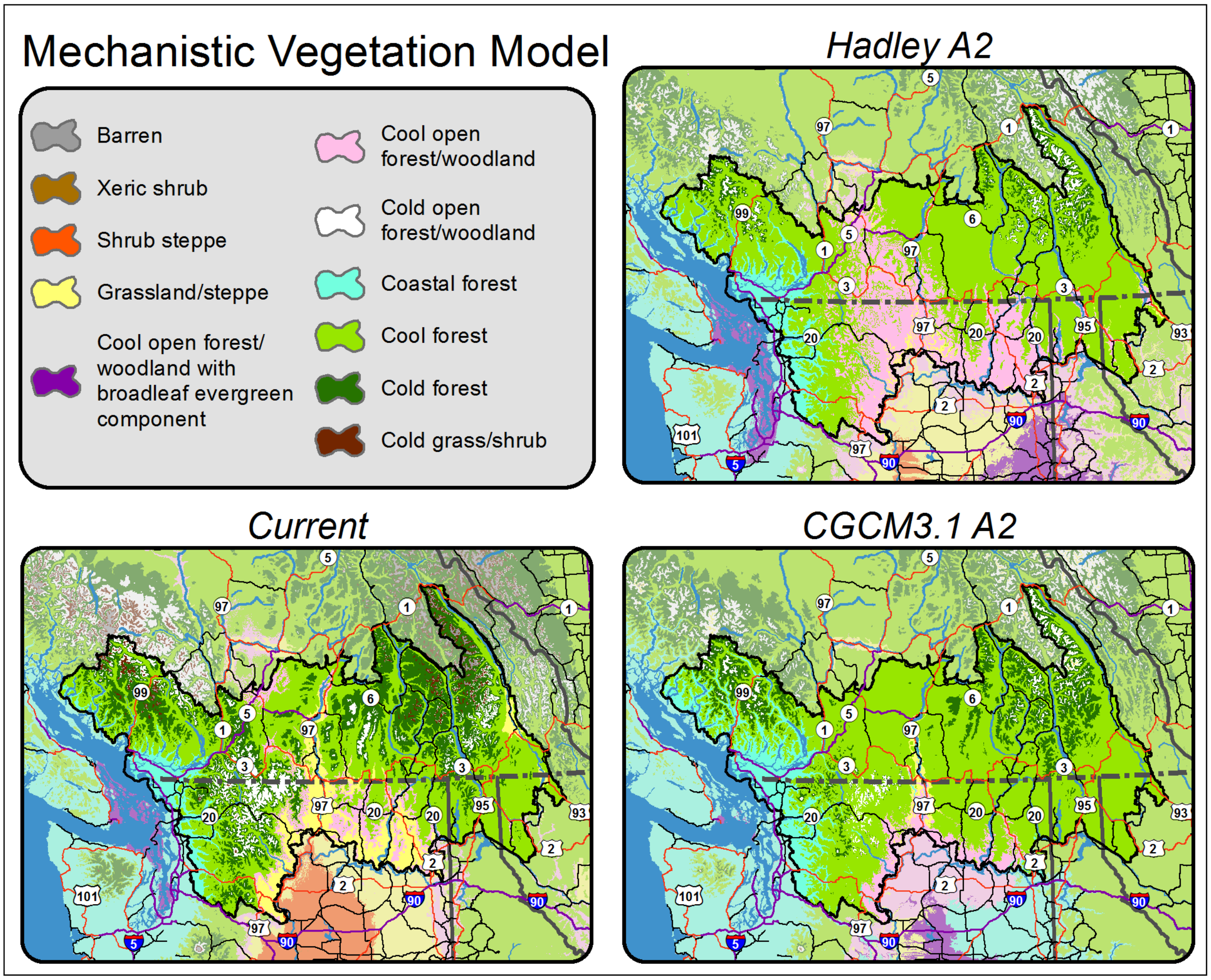
Appendix C.3b. Mechanistic Vegetation Model

ii) Extent: Okanagan-Kettle Region



Appendix C.3b. Mechanistic Vegetation Model

iii) Extent: Washington-British Columbia Transboundary Region



Appendix C.4. Projected Changes in Relevant Climate Variables

The following projections of future climate were identified by project partners as being most relevant to understanding and addressing climate impacts on white-tailed ptarmigan connectivity.[xii] Future climate projections were gathered from two sources, except where otherwise noted: 1) the Integrated Scenarios of the Pacific Northwest Environment,[11] which is limited to the extent of the Columbia Basin; and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[12] which spans the full transboundary region. For many climatic variables, noticeable differences in the magnitude of future changes can be seen at the US-Canada border; this artifact results from differences on either side of the border in the number of weather stations, the way temperature and precipitation were measured, and differences in the approach used to process these data to produce gridded estimates of daily weather variations.

a) **Spring (April 1st) Snowpack.** This map snows the percent change in snow water equivalent (SWE) on April 1st. April 1st is the approximate current timing of peak annual snowpack in Northwest mountains. SWE is a measure of the total amount of water contained in the snowpack. Projected decreases in SWE are depicted by the yellow to red shading.

b) **Length of Snow Season.** This map shows the projected change in the length of the snow season, defined as the number of days between the first and last days of the season with at least 10% of annual maximum snow water equivalent. Projected changes in snow season length are depicted by the yellow to red shading.

c) **Increase in Average Annual Daytime Temperature.** This map shows the projected change in average annual summer (June-August) temperature in degrees Celsius. Projected temperature increases are depicted by the yellow to orange shading.

d) **Days with High Fire Risk** (Energy Release Component, ERC > 95th percentile).[xiii] This map shows the projected change in the number of days when the ERC – a commonly used metric to project the potential and risk of wildfire – is greater than the historical 95th percentile among all daily values.

e) **Total Spring Precipitation, March-May.** This map shows the projected change, in percent, in total spring (March-May) precipitation. Projected changes in total spring precipitation are depicted by the yellow to green shading.

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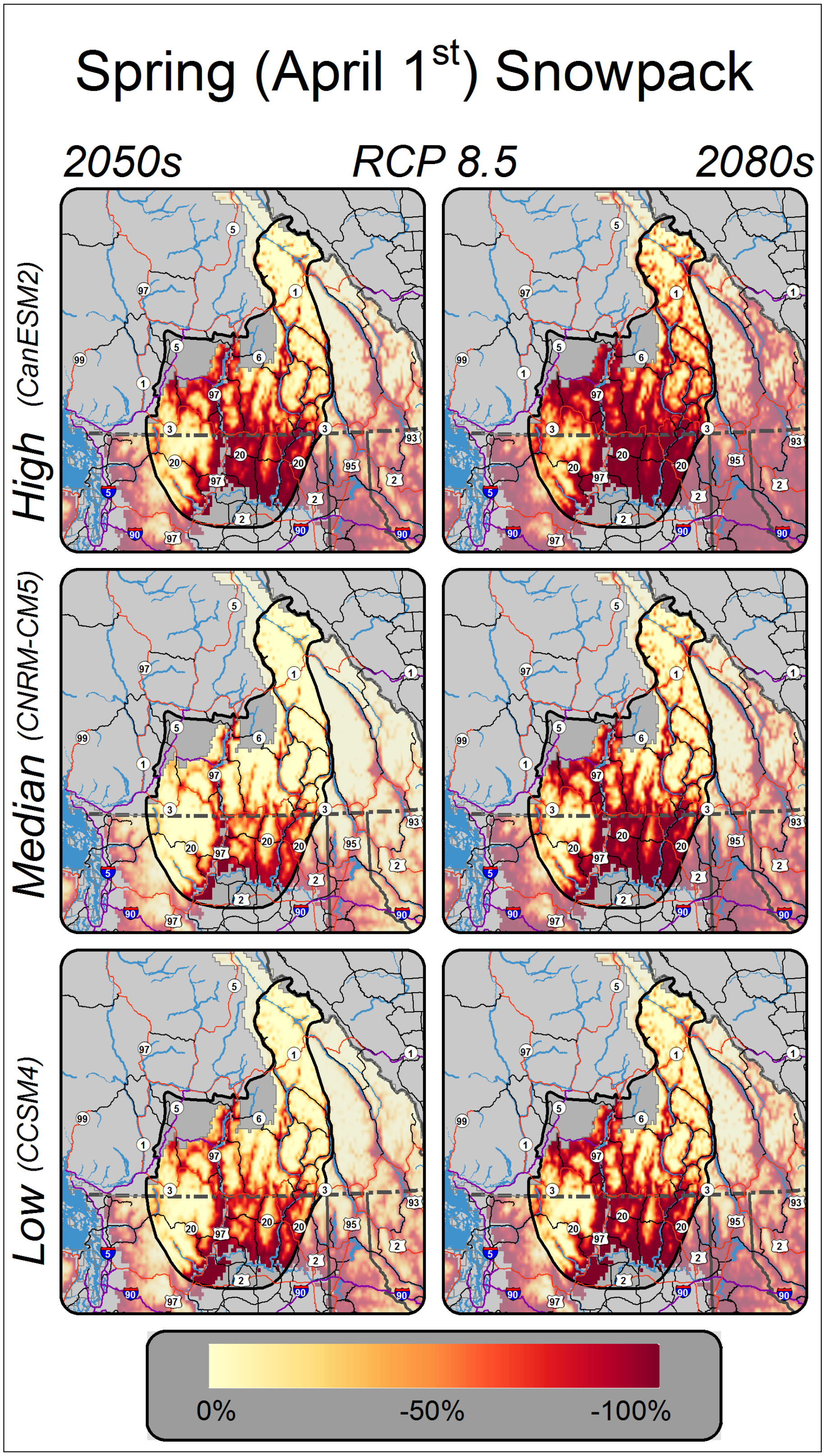
xii All projections but "Days with High Fire Risk" are evaluated for the 2050s (2040-2069) and the 2080s (2070-2099), based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (CCSM4)), under a high greenhouse gas scenario (RCP 8.5). "Days with High Fire Risk" is evaluated for the 2050s, based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (MIROC5)) using the RCP 8.5 (high) emissions scenario.

xiii Abatzoglou, J.T. 2013. Development of gridded surface meteorological data for ecological applications and modeling. *International Journal of Climatology*, 33(1): 121-131.

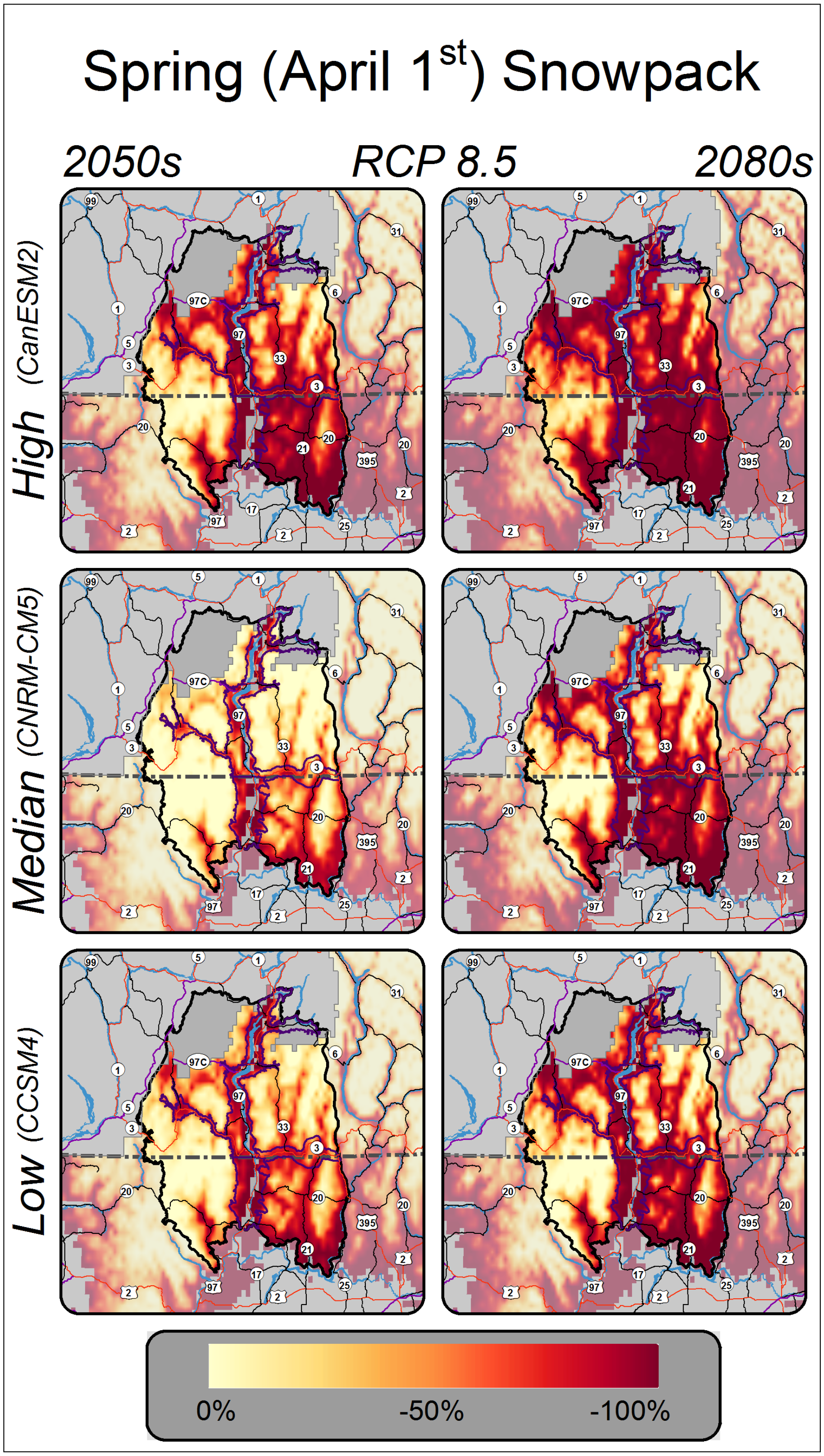
Appendix C.4a. Spring (April 1st) Snowpack

i) Extent: Okanagan Nation Territory



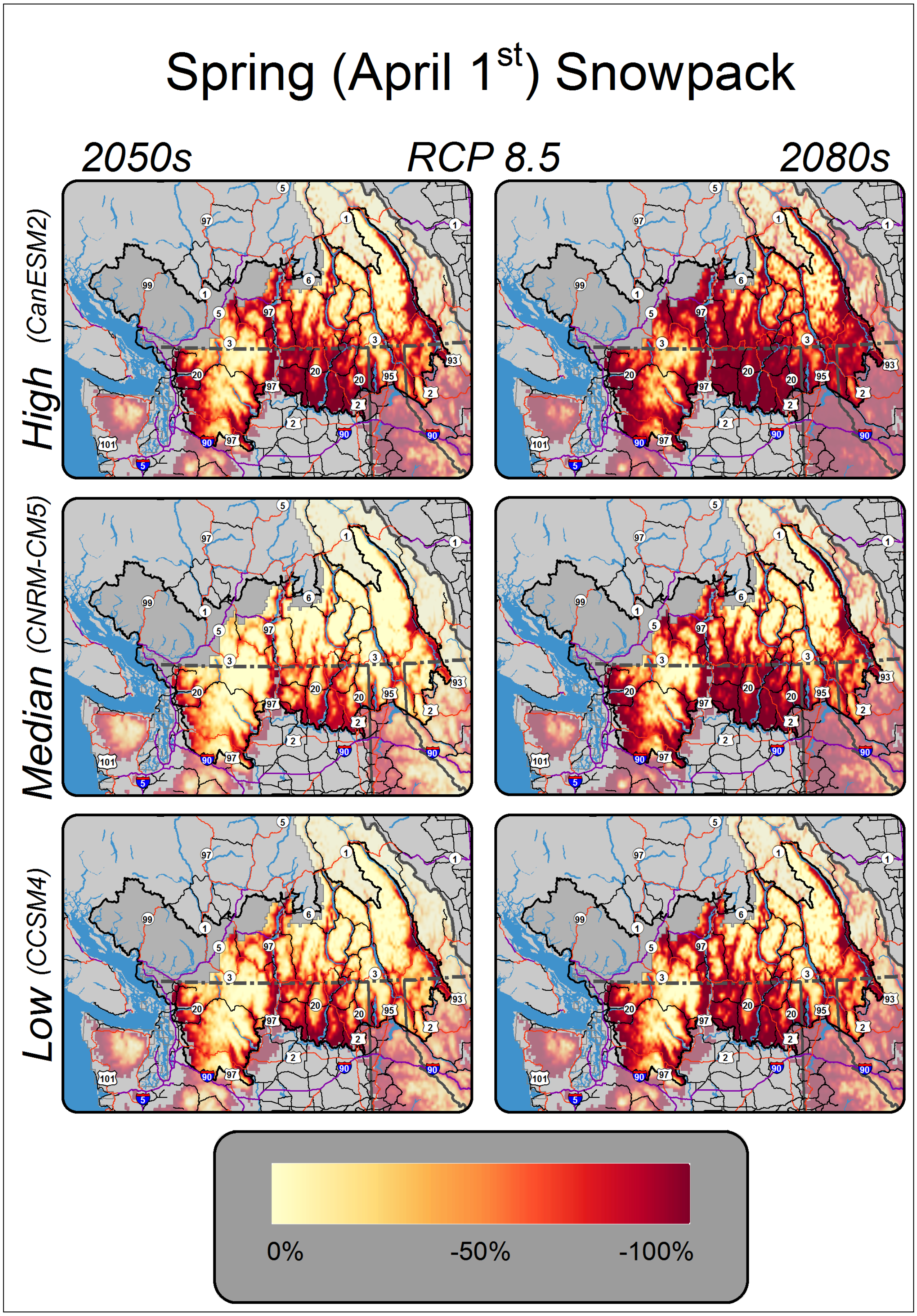
Appendix C.4a. Spring (April 1st) Snowpack

ii) Extent: Okanagan-Kettle Region



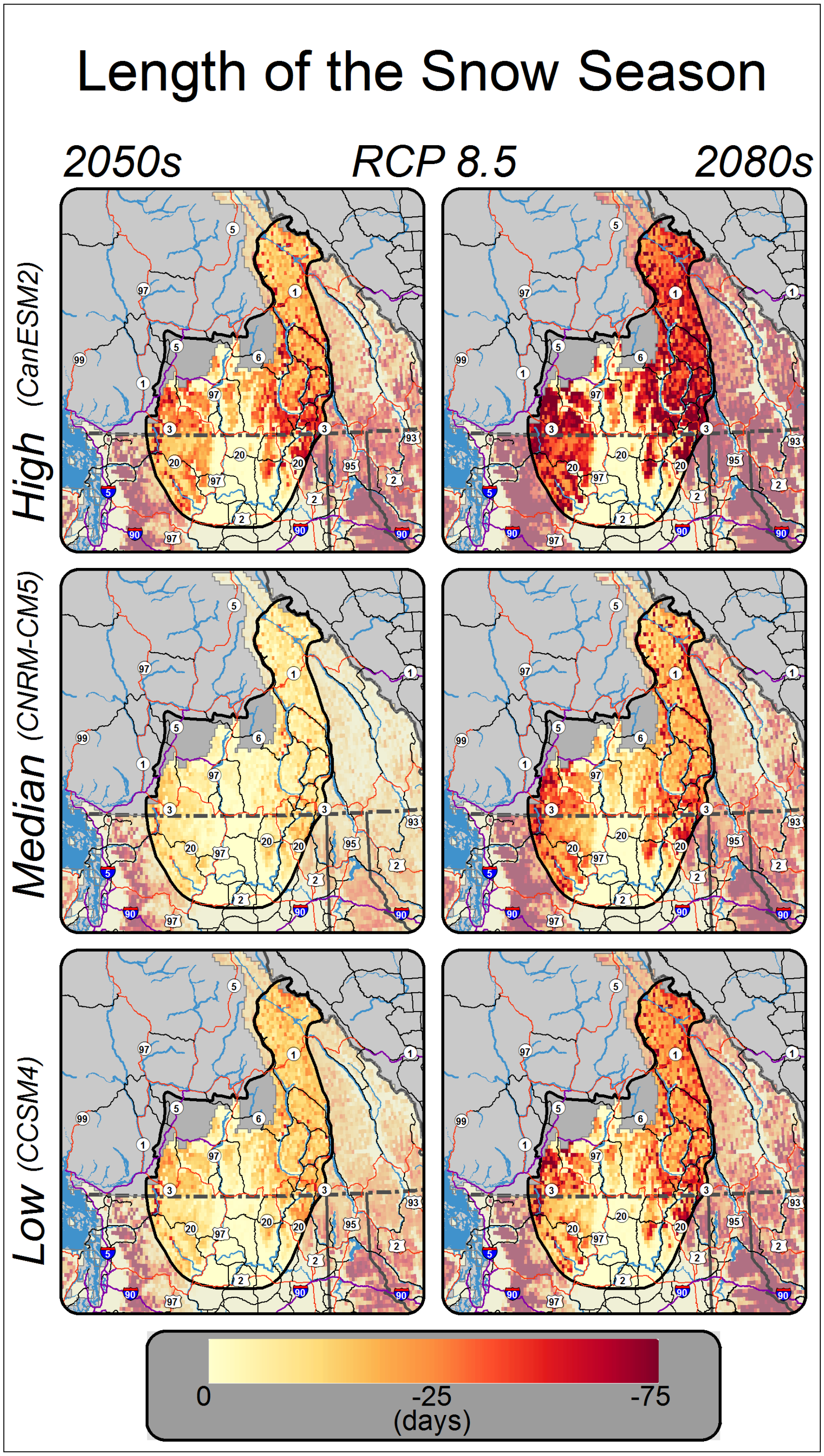
Appendix C.4a. Spring (April 1st) Snowpack

iii) Extent: Washington-British Columbia Transboundary Region



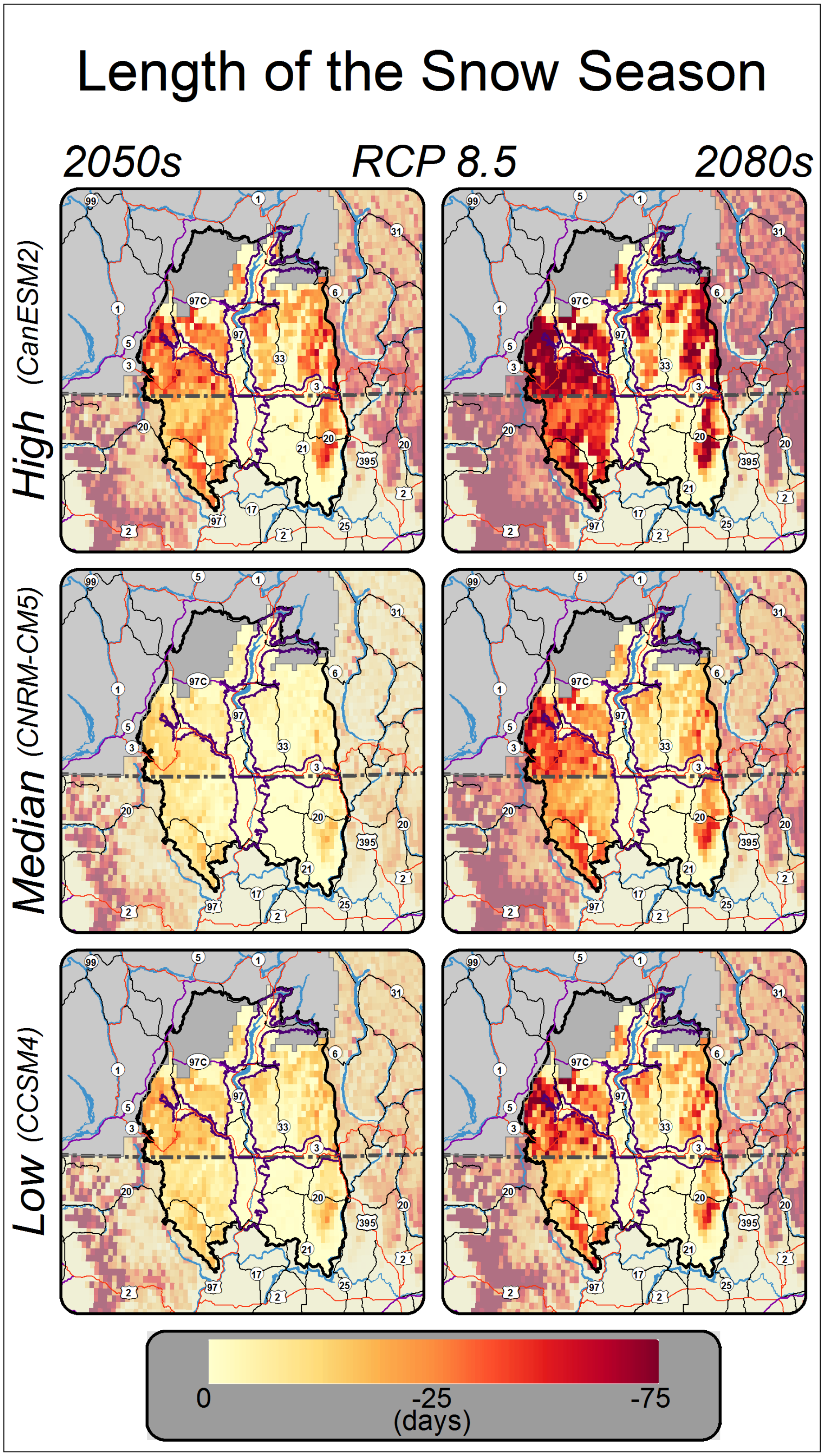
Appendix C.4b. Length of Snow Season

i) Extent: Okanagan Nation Territory



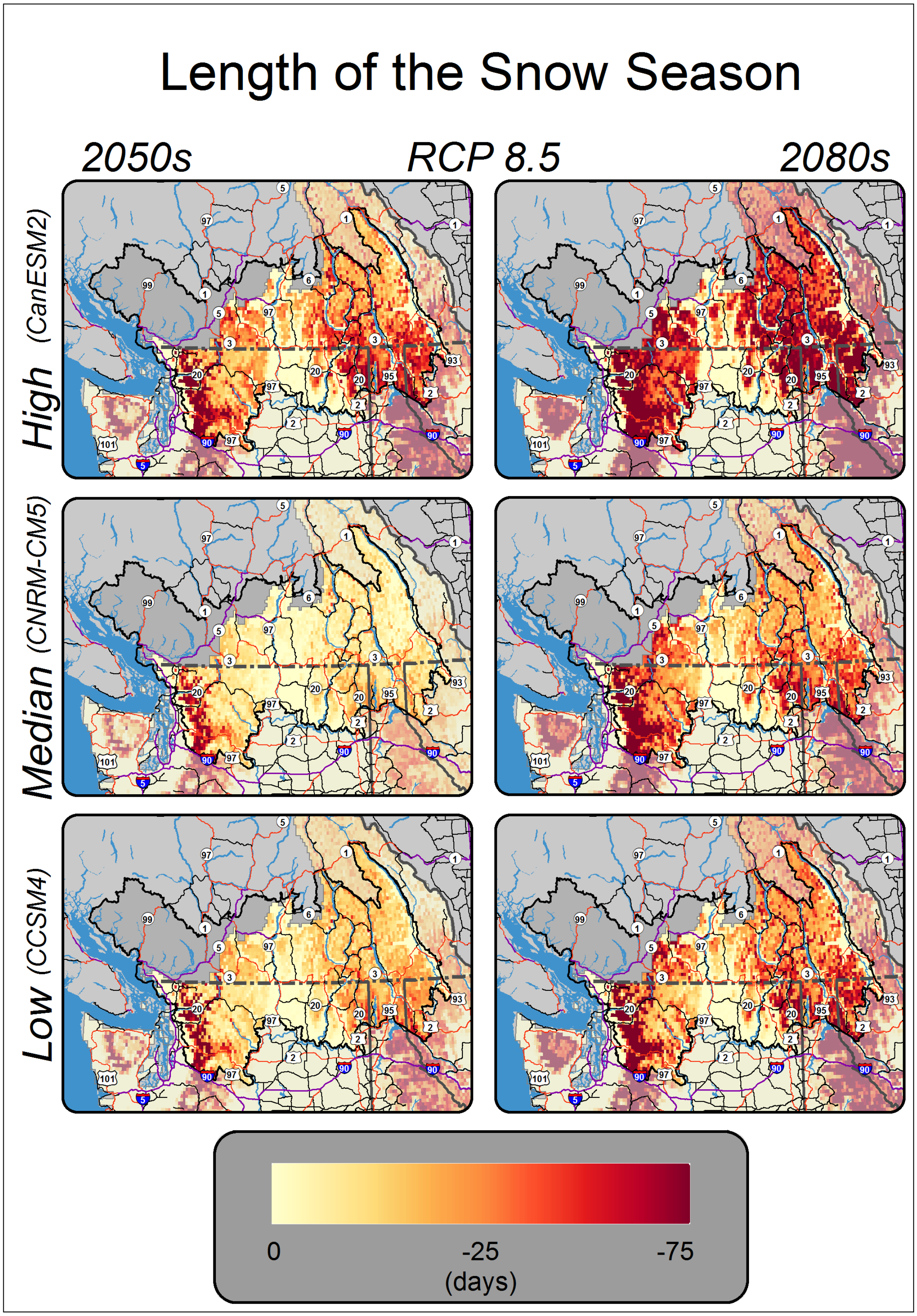
Appendix C.4b. Length of Snow Season

ii) Extent: Okanagan-Kettle Region



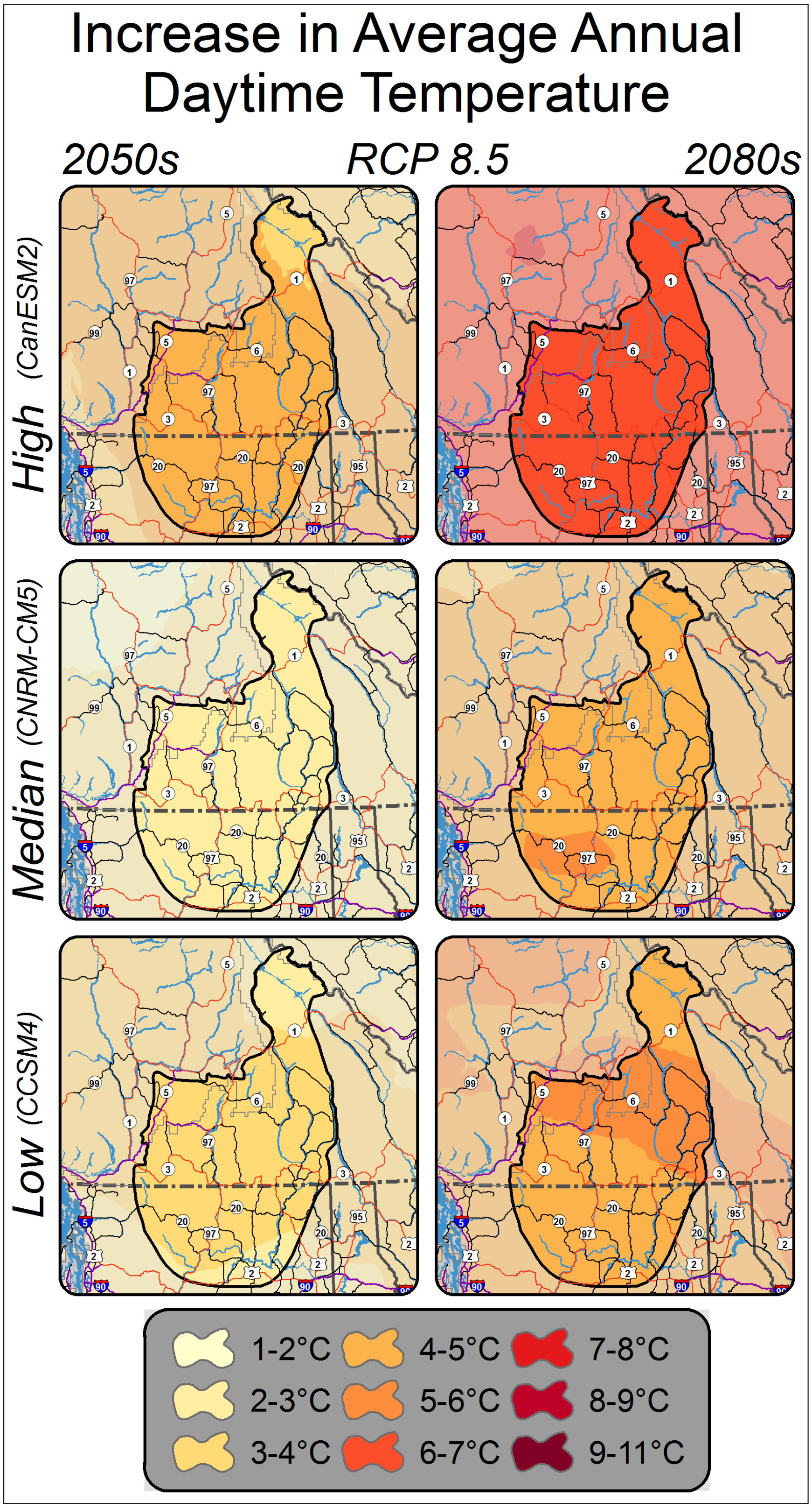
Appendix C.4b. Length of Snow Season

iii) Extent: Washington-British Columbia Transboundary Region



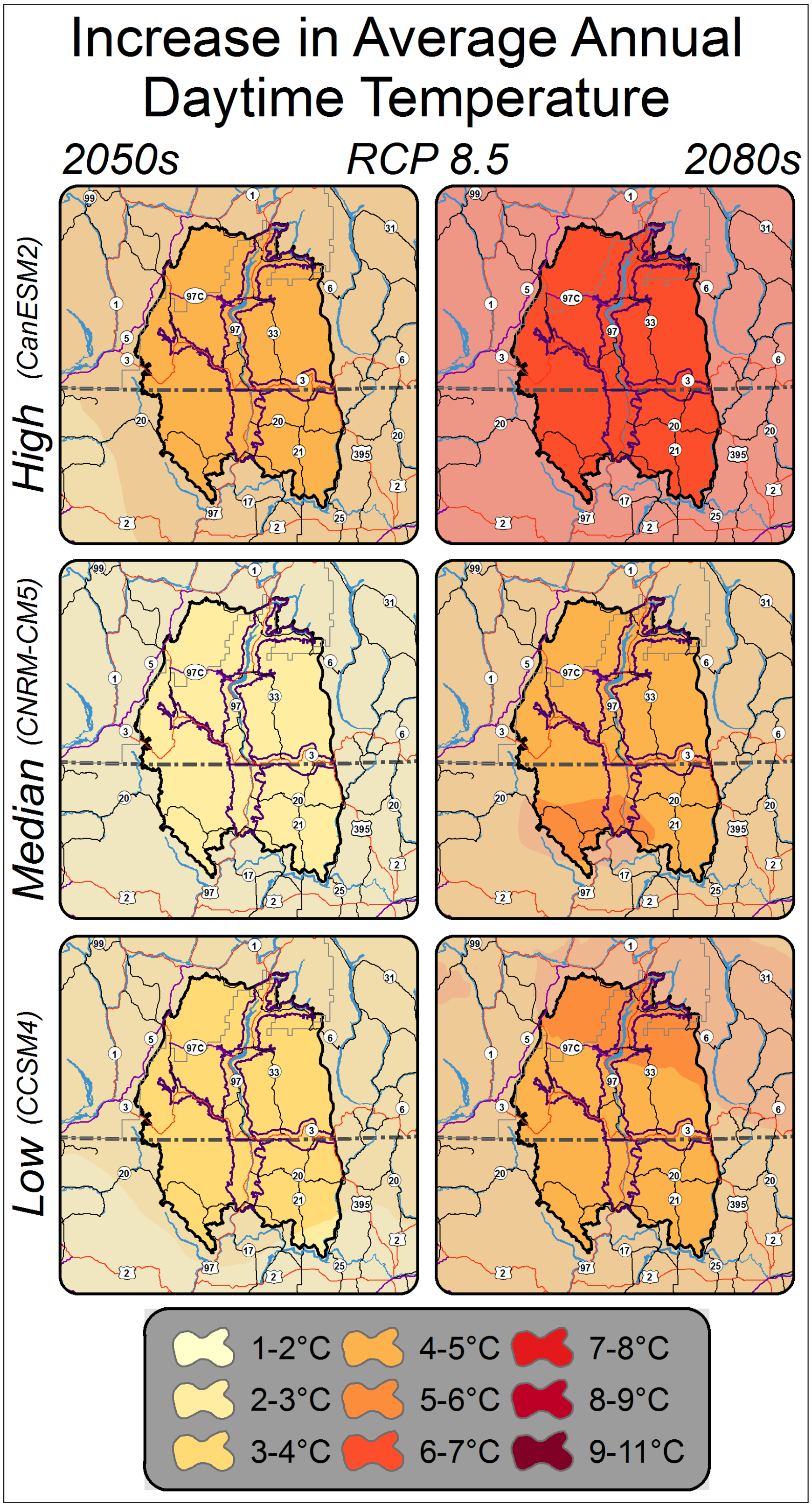
Appendix C.4c. Increase in Average Annual Daytime Temperature

i) Extent: Okanagan Nation Territory



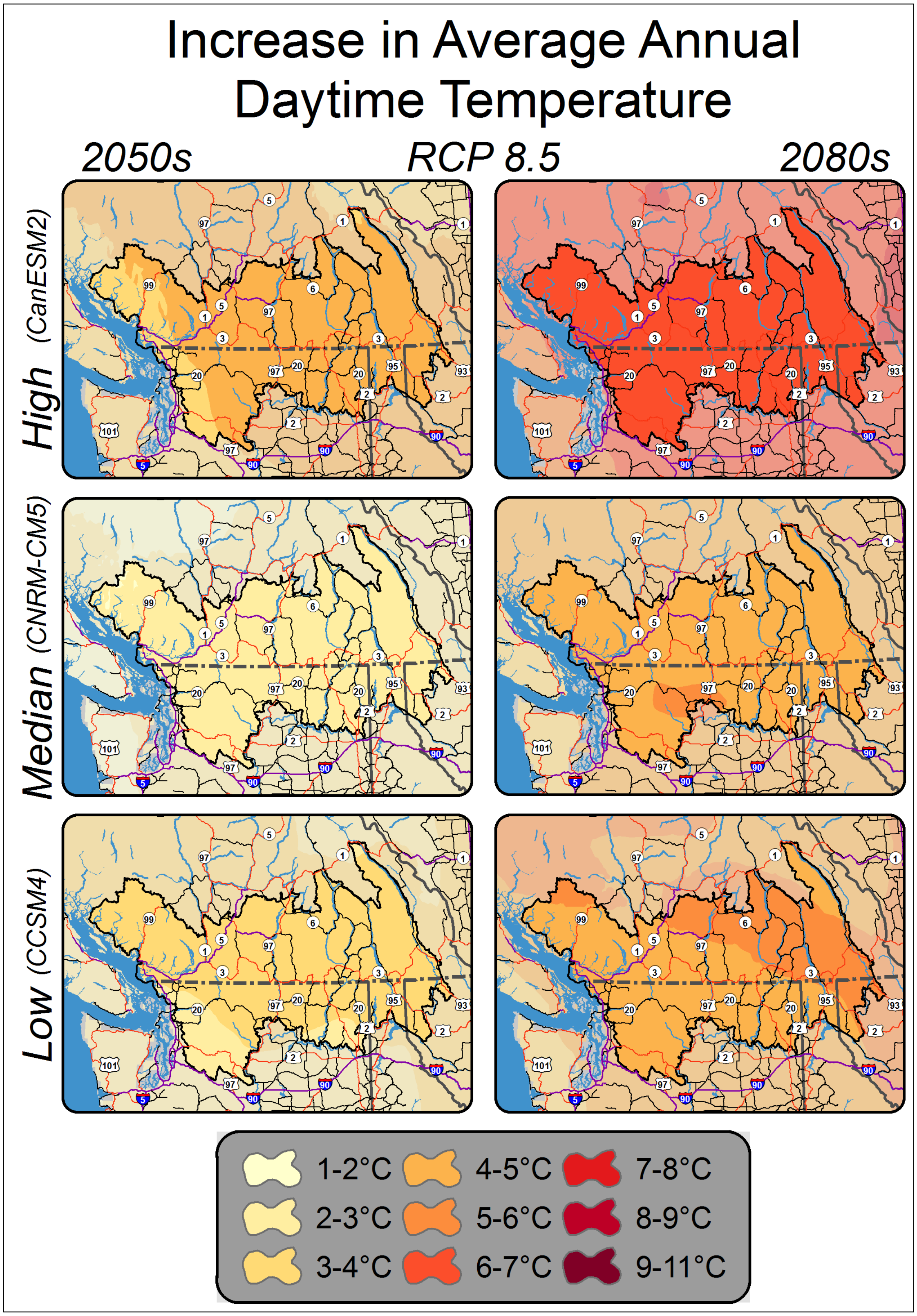
Appendix C.4c. Increase in Average Annual Daytime Temperature

ii) Extent: Okanagan-Kettle Region



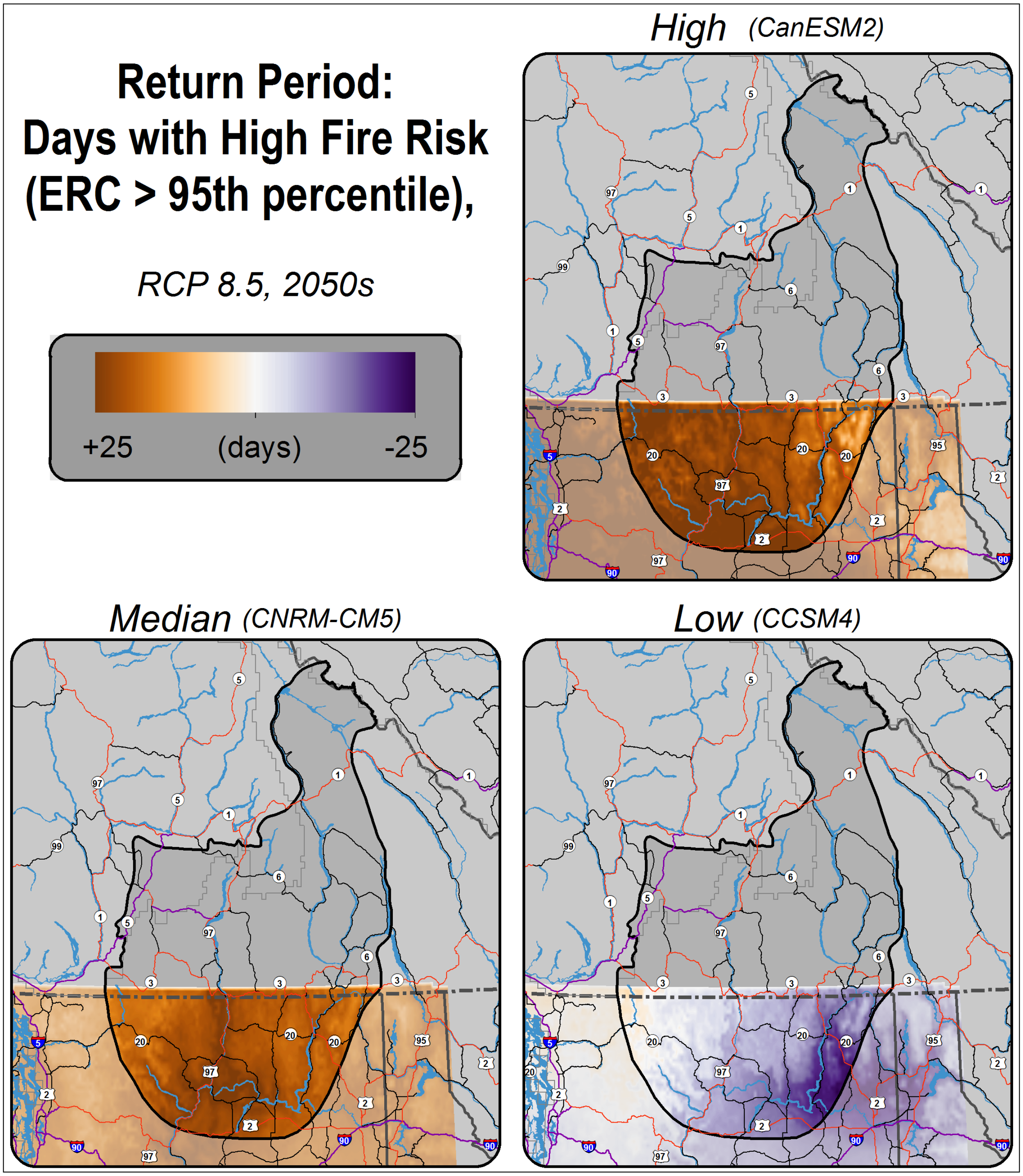
Appendix C.4c. Increase in Average Annual Daytime Temperature

iii) Extent: Washington-British Columbia Transboundary Region



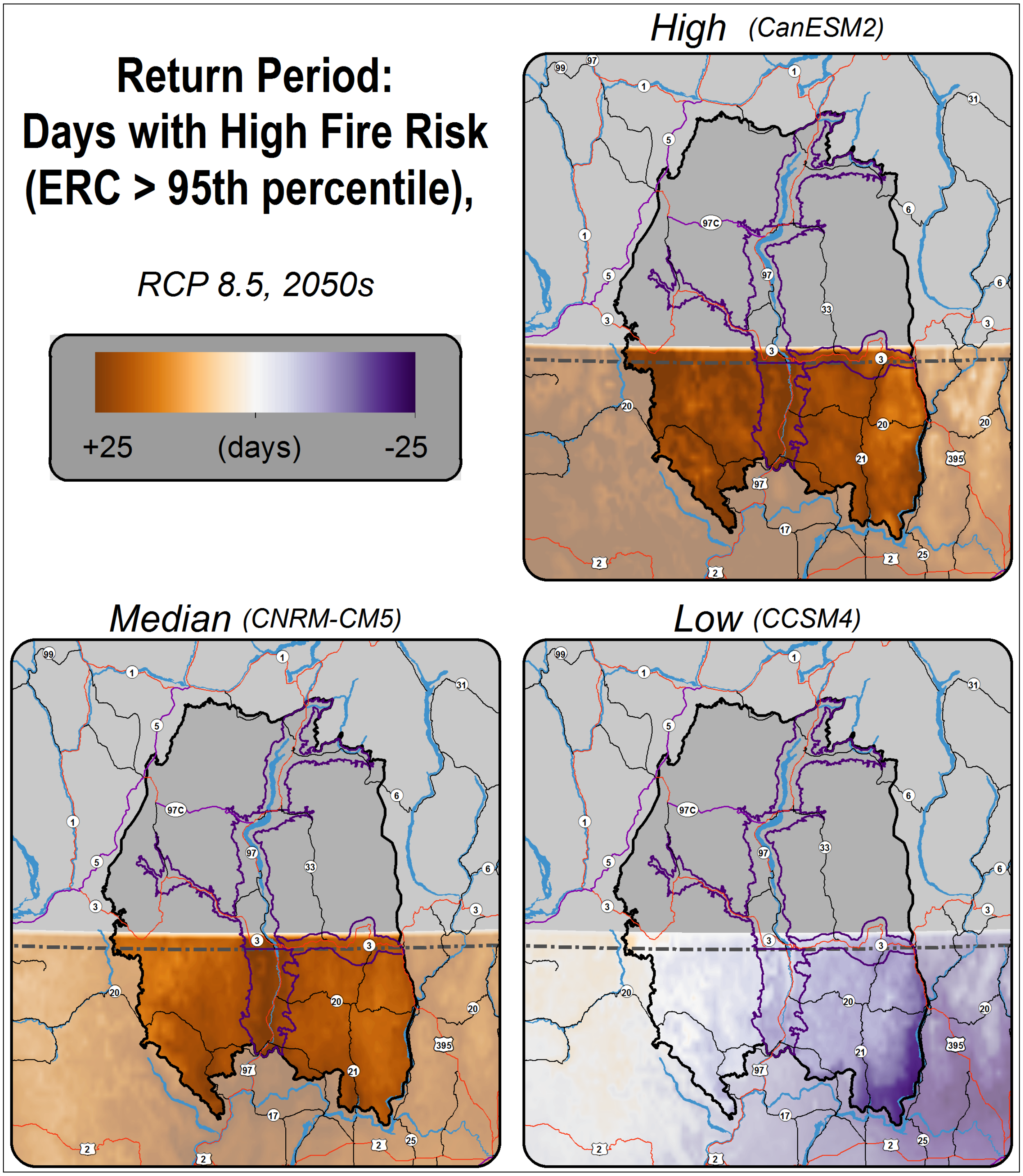
Appendix C.4d. Days with High Fire Risk

i) Extent: Okanagan Nation Territory



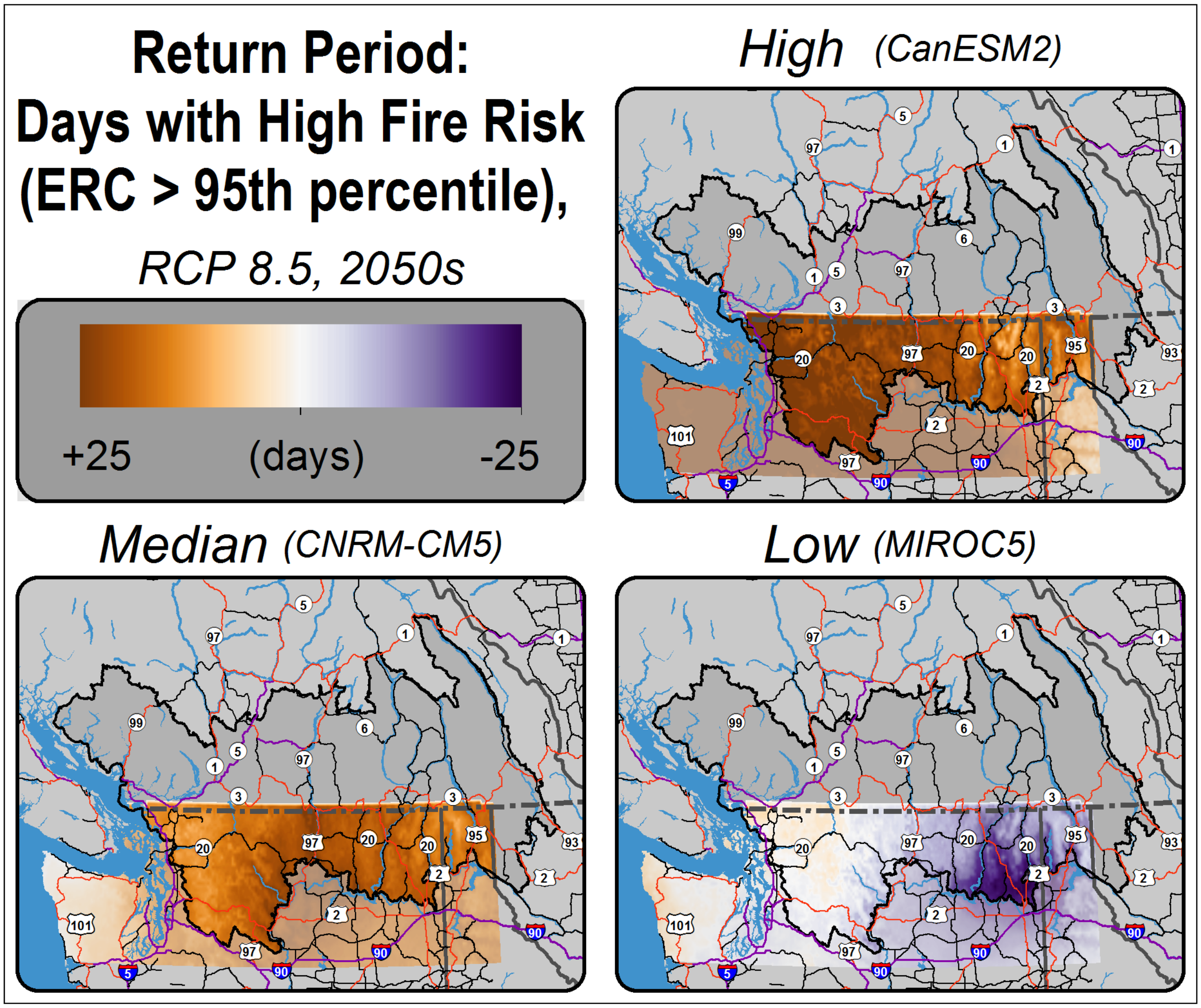
Appendix C.4d. Days with High Fire Risk

ii) Extent: Okanagan-Kettle Region



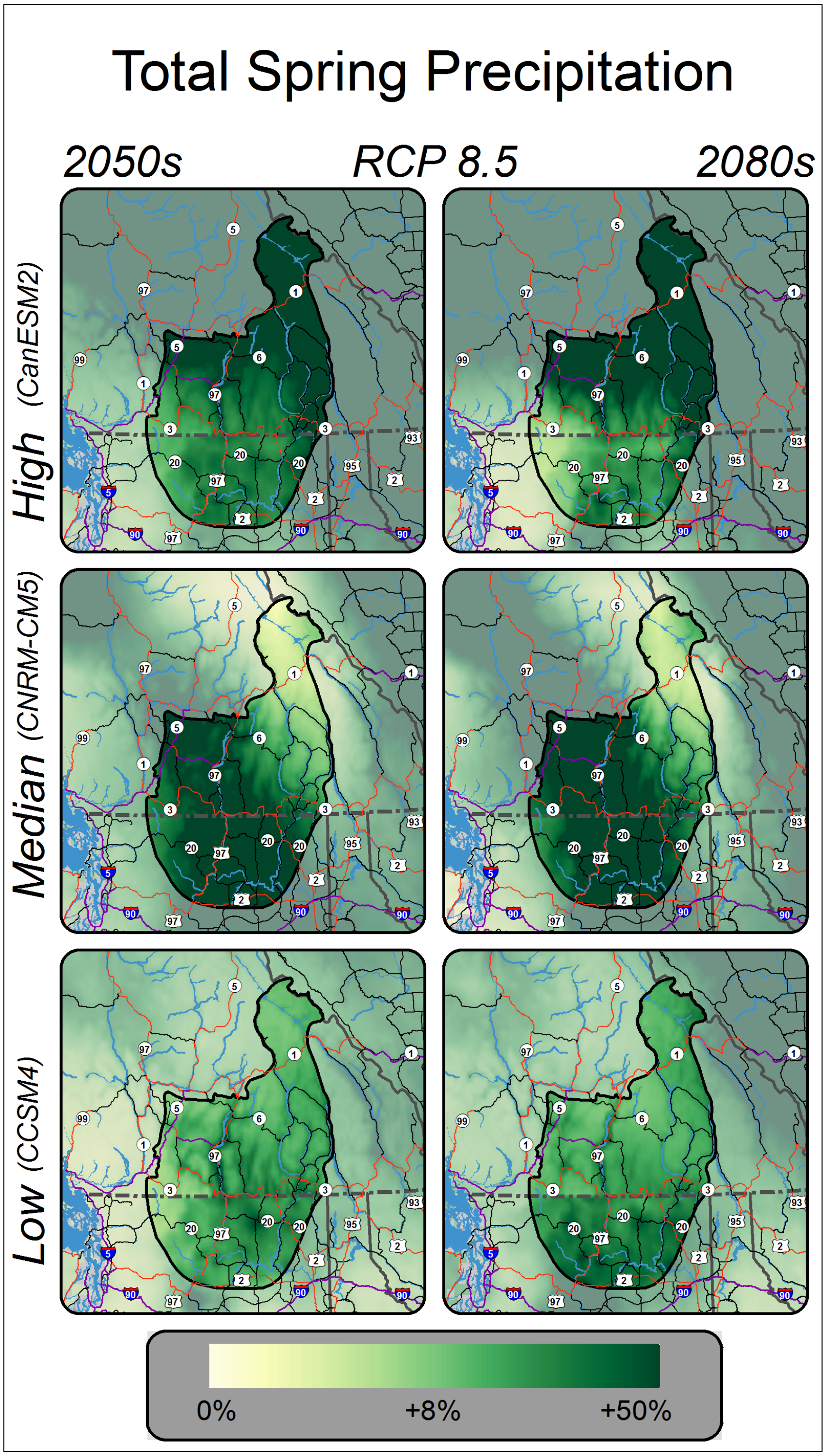
Appendix C.4d. Days with High Fire Risk

iii) Extent: Washington-British Columbia Transboundary Region



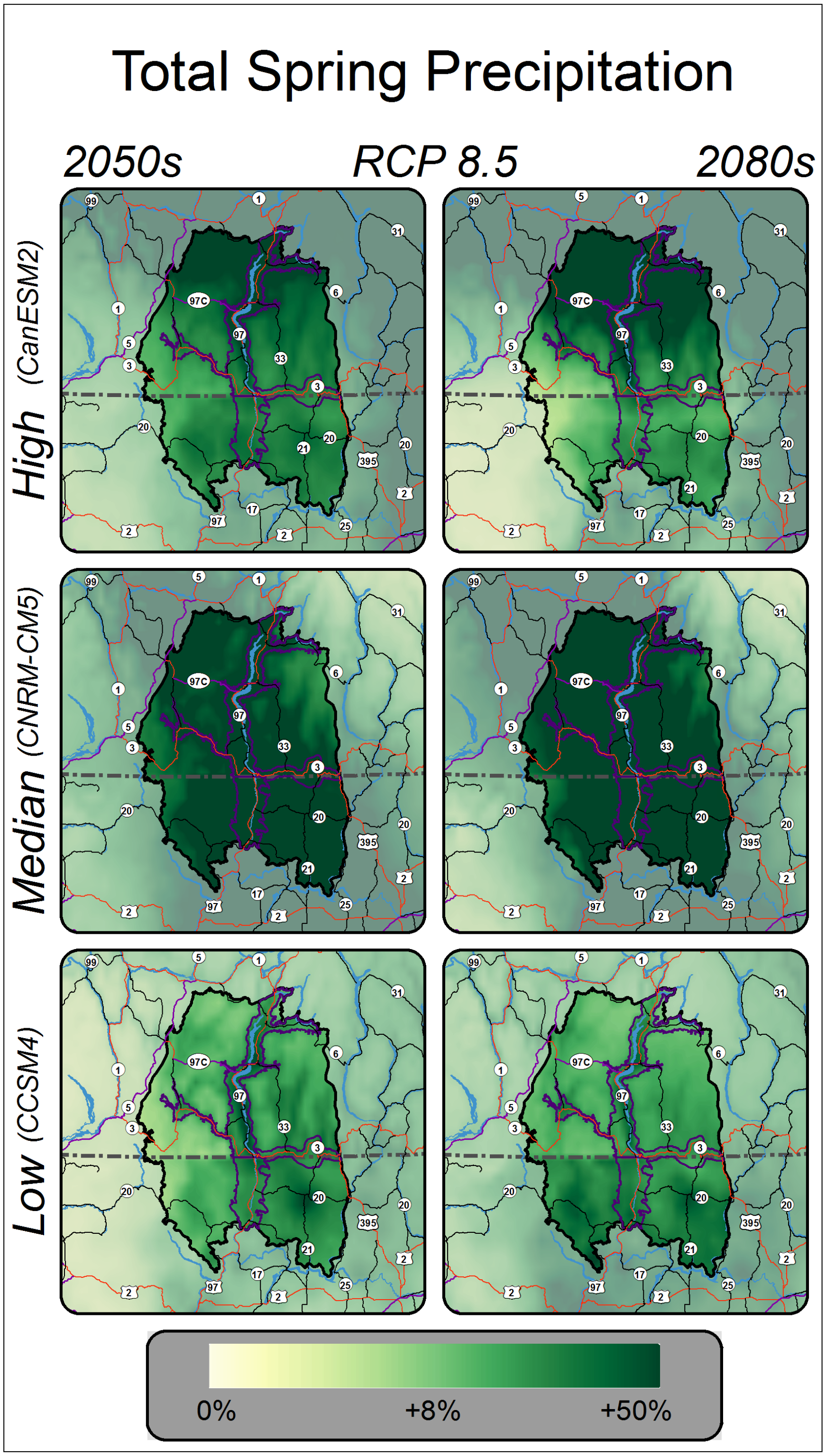
Appendix C.4e. Total Spring Precipitation, March-May

i) Extent: Okanagan Nation Territory



Appendix C.4e. Total Spring Precipitation, March-May

ii) Extent: Okanagan-Kettle Region



Appendix C.4e. Total Spring Precipitation, March-May

iii) Extent: Washington-British Columbia Transboundary Region